



department of Conservation and Recreation

**Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management**

**Water Quality Report: 2004
Wachusett Reservoir and Watershed**

March 2004

ABSTRACT

The Metropolitan District Commission Division of Watershed Management (now known as the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management) was established by Chapter 372 of the Acts of 1984. The Division was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the new Office of Watershed Management. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2004 water quality data from the Wachusett watershed. A report summarizing 2004 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

Acknowledgements:

This plan was prepared by the staff of the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management. Principal authors are Lawrence Pistrang, Environmental Analyst, Wachusett/Sudbury Section and David Worden, Aquatic Biologist, Wachusett/Sudbury Section. Internal review was provided by Pat Austin. Frank Battista, David Worden, David Getman, and Lawrence Pistrang collected the samples and were responsible for all fecal coliform analysis through June 2004. All bacterial analyses after this date were done at the MWRA Lab in Southboro.

DCR/DWSP/OWM thanks the staff and management of the MWRA Deer Island Lab for preparing and delivering sample bottles and performing all nutrient analyses during the year. They also thank MWRA staff at the Southboro Lab for performing all coliform analyses during the latter half of the year.

All maps were produced by DCR/DWSP/OWM GIS analyst Craig Fitzgerald, using the most recent data.

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WACHUSETT RESERVOIR
2004 WATER QUALITY DATA
CHEMICAL, PHYSICAL, BACTERIAL

<u>PARAMETER</u>	<u>REPORTING UNITS</u>
Temperature	degrees Centigrade
Depth	meters
Dissolved Oxygen	mg/L
Conductivity	µmhos/cm
pH	units
Alkalinity	mg/L as CaCO ₃
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Kjeldahl Nitrogen	mg/L
Silica	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL

WACHUSETT RESERVOIR

2004 PHYTOPLANKTON DATA

PARAMETER

Plankton Concentration

REPORTING UNITS

Areal Standard Units per mL

WACHUSETT RESERVOIR WATERSHED
2004 TRIBUTARY WATER QUALITY DATA
CHEMICAL, PHYSICAL, BACTERIAL

<u>PARAMETER</u>	<u>REPORTING UNITS</u>
Temperature	degrees Centigrade
Depth	feet
Flow	cubic feet per second
Conductivity	µmhos/cm
Nitrate-Nitrogen	mg/L
Ammonia-Nitrogen	mg/L
Total Phosphorus	mg/L
Fecal Coliform	colonies/100mL
Metals	mg/L or µg/L

WATER QUALITY REPORT: 2004

WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Metropolitan District Commission Division of Watershed Management (now known as the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management) was established by Chapter 372 of the Acts of 1984. The OWM was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The OWM and the MWRA currently have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the OWM's watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. OWM staff also sample to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from a total of fifty-four stations on thirty tributaries and from four stations on the reservoir. This was a significant increase from the previous few years and the most stations sampled in a single year. Weekly or twice weekly collection of Wachusett Reservoir plankton was done from the back of the Cosgrove Intake (through March) or from a boat at Station 3417 (Basin North) in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Temperature, pH, dissolved oxygen, and conductivity profiles were taken in conjunction with plankton sampling; quarterly profiles were also measured at two additional reservoir stations. Fecal coliform samples were collected from reservoir surface stations, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

All bacteria data collected before June 14th were recorded in permanent laboratory books and also are part of a DCR electronic database (Microsoft Excel file Fc_dbase2004.xls) located at the DCR-OWM Water Quality Laboratory in West Boylston, Massachusetts. Bacteria data collected on and after June 14th and all nutrient data reside on the MWRA LIMS and in DCR electronic files. Results of tributary and reservoir water quality testing are discussed by parameter in sections 3.1 – 4.4. All water quality data are included as appendices to this report.

The Pinecroft Area drainage basin is being investigated to evaluate the impacts of sewerage on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Gates Brook prior to sewer construction. Samples were also collected in similarly sized subbasins with different land uses for comparative purposes. Weekly sampling of the three subbasins continued in 2004. Data collected as part of this study are included in this report. Approximately 75% of the homes in the Pinecroft neighborhood are now connected to the municipal sewer and water quality in the subbasin is expected to improve dramatically. An analysis is included as part of this water quality report.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attempted to communicate with conservation commission and board of health members on a regular basis to provide technical assistance and to gain advance knowledge of proposed activities. All investigations and projects were documented as part of a comprehensive filing system.

In an effort to refine the process of threat assessment within the Wachusett watershed, Environmental Quality staff divided the watershed into five sanitary districts with the goal of completing a detailed assessment of one district per year on a five-year rotating basis. Information was gathered on hydrology, natural resources, demographics, land use, historic water quality, and both actual and potential threats for the fourteen subbasins within the Quinapoxet District. A district overview with detailed information presented in fourteen individual subbasin chapters was prepared, and both general and specific recommendations were developed. The Quinapoxet District Environmental Quality Assessment was published under separate cover in August 2004. Similar data gathering activities were initiated during fall 2004 for the subbasins of the Stillwater District, with publication expected during 2005.

Samples were also collected from additional locations to investigate potential water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations. Water samples were collected during both dry and wet conditions, usually from several locations on a single tributary, to help locate pollution sources. Monthly samples were collected from two stations on Gates Brook to provide baseline data for a UMASS stormwater monitoring project. All data collected are included in this report.

2.0 DESCRIPTION OF WATERSHED MONITORING PROGRAM

Wachusett Environmental Quality staff collected routine water quality samples from fifty-four stations on thirty tributaries and from four stations on the reservoir during 2004. This was a significant increase from the previous few years and the most stations sampled in a single year. The stations are described below in Table 1 and are located on Figure 1. Additional stations were sampled occasionally to support special studies or potential enforcement actions. Nearly 3000 samples were analyzed in-house including a total of 2835 bacteria samples and more than 100 plankton samples. Almost 4000 physiochemical measurements were done in the field or at the DCR lab. In addition, 1671 samples were collected and delivered to the MWRA laboratory in Southboro for fecal coliform analysis, and seventy-nine samples were collected and shipped to the MWRA Deer Island laboratory for nearly 1500 analyses of nutrients and metals.

Each tributary station was visited weekly throughout the entire year. Temperature and conductivity were measured in the field (except during extreme cold temperatures) using a Corning CD-30 or YSI Model 30 conductivity meter and samples were collected for fecal coliform analysis. All fecal coliform analyses were done at the DCR lab in John Augustus Hall in West Boylston until mid June; samples collected after June 14th until the end of the year were delivered to the MWRA Southboro Lab for analysis. Quarterly samples for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, UV-254, and total organic carbon were collected in May, October, and December from nine stations and analyzed at the MWRA Deer Island Lab. Monthly samples (April-December, none in August) for the same set of parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Temperature, dissolved oxygen, pH, and conductivity profiles were measured weekly at Station 3417 (Basin North) or the Cosgrove Intake in conjunction with routine plankton monitoring, and quarterly at Station 3412 (Basin South) and Thomas Basin. Quarterly samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, alkalinity, total phosphorus, and UV-254 were collected at the same stations from the epilimnion, metalimnion, and hypolimnion and analyzed at the MWRA Lab at Deer Island.

Fecal coliform samples were collected Monday through Thursday from the reservoir surface at the Cosgrove Intake to help monitor the effect of weather conditions, tributary inputs, and migratory bird populations on bacteria concentrations. Sampling was discontinued in mid June once the DCR lab ceased operations. The MWRA continues to collect a regulatory sample from the Cosgrove Intake five times per week. Fecal coliform samples were collected once or twice per month at twenty-three reservoir locations (Figure 2) to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on birds and bacteria concentrations.

TABLE 1 (part one of two)

ROUTINE WACHUSETT SAMPLING STATIONS – 2004

<u>STATION</u>	<u>LOCATION</u>	<u>FREQUENCY</u>
1. Asnebumskit (Mill)	upstream of Mill Street, Holden	W
2. Asnebumskit (Prin)	upstream of Princeton Street, Holden	W
3. Ball Brook	Route 140, Sterling	W
4. Beaman 2	Route 110, W. Boylston (homes)	W
5. Beaman 3	Route 110, W. Boylston (muskrat)	W
6. Beaman 3.5	Route 110, W. Boylston (horses)	W
7. Boylston Brook	Route 70, Boylston	W
8. Chaffins (Malden)	Malden Street, Holden	W
9. Chaffins (Poor Farm)	Newell Road, Holden	W
10. Chaffins (Unionville)	Unionville Pond outlet, Holden	W
11. Chaffins (Wachusett)	Wachusett Street, Holden	W
12. Cook Brook (Wyoming)	Wyoming Street, Holden	W, Q
13. East Wachusett (140)	Route 140, Sterling	W
14. East Wachusett (31)	Route 31, Princeton	W
15. East Wachusett (Bull)	Bullard Road, Princeton	W
16. French Brook (70)	Route 70, Boylston	W, Q
17. Gates Brook (1)	Gate 25, W.Boylston	W, Q
18. Gates Brook (2)	Route 140, W.Boylston	W
19. Gates Brook (3)	Worcester Street, W.Boylston	W
20. Gates Brook (4)	Pierce Street, W.Boylston	W
21. Gates Brook (6)	Lombard Avenue, W.Boylston	W
22. Gates Brook (9)	Woodland Street, W.Boylston	W
23. Hastings Cove Brook	Route 70, Boylston	W
24. Hog Hill Brook	Laurel Street, Holden	W
25. Houghton Brook	Route 140, Sterling	W
26. Jordan Farm Brook	Route 68, Rutland	W
27. Justice Brook	Route 140, Sterling/Princeton line	W
28. Keyes (Gleason)	Gleason Road, Princeton	W
29. Keyes (Hobbs)	Hobbs Road, Princeton	W

D = daily (bacteria Monday – Thursday)

W = weekly (bacteria, temperature, conductivity [tributaries], algae and profiles [Cosgrove or 3417])

M = monthly (nutrients and metals)

Q = quarterly (algae and profiles [reservoir], nutrients [reservoir and tributaries])

TABLE 1 (part two of two)

ROUTINE WACHUSETT SAMPLING STATIONS – 2004

<u>STATION</u>	<u>LOCATION</u>	<u>FREQUENCY</u>
30. Keyes (Onion)	behind Quik-Stop, Route 140, Princeton	W
31. Malagasco Brook	West Temple Street, Boylston	W, Q
32. Malden Brook	Thomas Street, W.Boylston	W, Q
33. Muddy Brook	Route 140, W.Boylston	W, Q
34. Oakdale Brook	Waushacum Street, W. Boylston	W
35. Quinapoxet River (CMills)	Canada Mills, Holden	W, M, Q
36. Quinapoxet River (dam)	above circular dam, W.Boylston	W
37. Quinapoxet River (Mill St)	Mill Street, Holden	W
38. Rocky Brook	Beaman Street, Sterling	W
39. Rocky (E Branch)	Justice Hill Road, Sterling	W, Q
40. Scanlon Brook	Crowley Road, Sterling	W
41. Scarlett Brook	Worcester Street, W.Boylston	W
42. Scarlett (Rt12)	Upstream of Walmart, W. Boylston	W
43. Stillwater (62)	Route 62, Sterling	W
44. Stillwater River (SB)	Muddy Pond Road, Sterling	W, M, Q
45. Swamp 15 Brook	Harris Street, Holden	W
46. Trout Brook	Manning Street, Holden	W
47. Warren Tannery Brook	Quinapoxet Street, Holden	W
48. Waushacum (Conn)	Jewett Road, Sterling	W
49. Waushacum (filter)	above filter beds, Route 12, Sterling	W
50. Waushacum (Fairbanks)	Fairbanks Street, Sterling	W
51. Waushacum (Pr)	Prescott Street, W.Boylston	W
52. Waushacum (WWP)	Gates Road, Sterling (pond outlet)	W
53. West Boylston Brook	Gate 25, W.Boylston	W, Q
54. Wilder Brook	Wilder Road, Sterling	W
A. 3409 (Reservoir)	Cosgrove Intake	D, W, Q
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	W, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	Q
D. TB (Reservoir)	Thomas Basin	Q

D = daily (bacteria Monday – Thursday)

W = weekly (bacteria, temperature, conductivity [tributaries], algae and profiles [Cosgrove or 3417])

M = monthly (nutrients and metals)

Q = quarterly (algae and profiles [reservoir], nutrients [reservoir and tributaries])

Figure 1
Sampling Stations

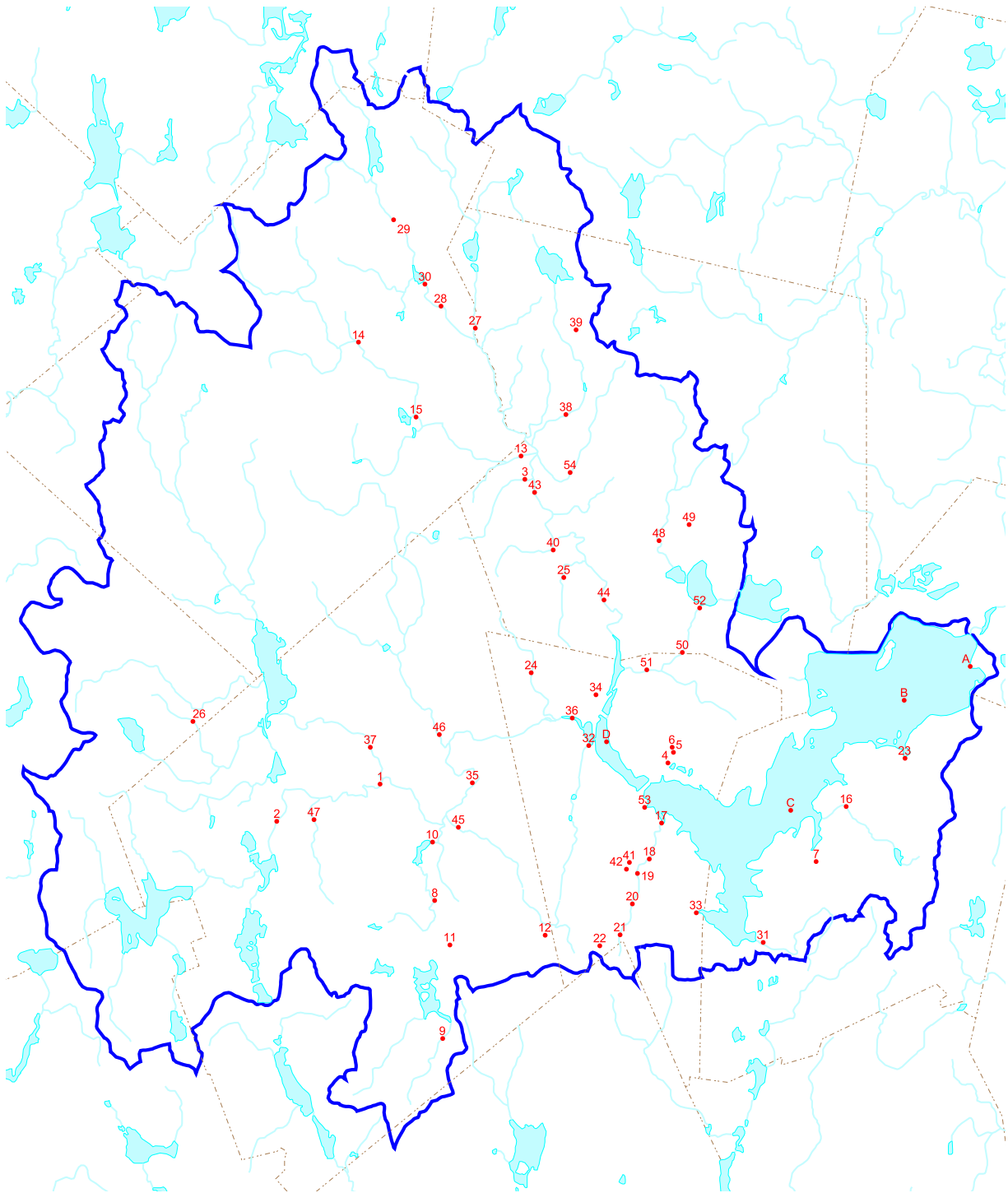


FIGURE 2

RESERVOIR TRANSECT STATIONS

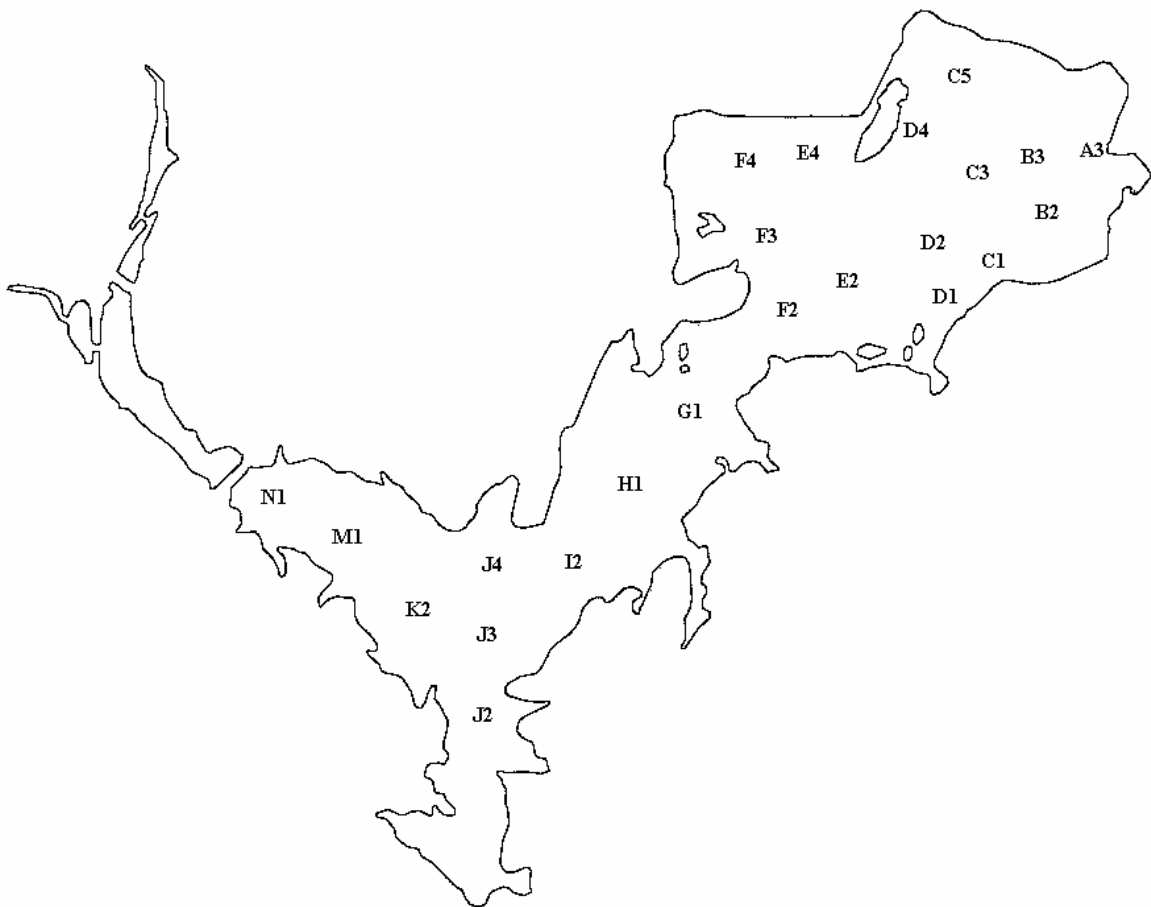


TABLE 2

**METHODS USED FOR FIELD AND LABORATORY ANALYSIS
WACHUSETT/SOUTHBORO/DEER ISLAND LABORATORIES**

<u>PARAMETER</u>	<u>STANDARD METHOD</u>
pH	Hydrolab Surveyor III
Conductivity	Corning CD-30 meter Hydrolab Surveyor III YSI Model 30 meter
Temperature	Hydrolab Surveyor III Corning CD-30 meter YSI Model 30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Total Phosphorus	EPA 365.1
Ammonia-Nitrogen	EPA 349.0
Nitrate-Nitrogen	EPA 353.4
Total Kjeldahl-Nitrogen	EPA 351.2
Silica	EPA 200.7
Dissolved Silica	EPA 200.7
UV254	SM 5910A SM5910B
Alkalinity	EPA 310.1 SM 2320B
Fecal Coliform	SM 9222 D
Algae	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

3.0 RESULTS OF TRIBUTARY MONITORING PROGRAM

3.1 BACTERIA

Fecal coliform concentrations were measured as an indicator of sanitary quality. Coliform density has been established as a significant measure of the degree of pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Fecal coliform are defined in Standard Methods for the Examination of Water and Wastewater - 20th edition (1999) as a subset of total coliform bacteria that produce blue colonies on M-FC media when incubated for 24 hours at 44.5° C. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. Fecal coliform are relatively easy to isolate in a laboratory, and direct counts can be made using membrane filtration. The presence of coliform bacteria in water suggests that there may be disease-causing agents present as well.

Fecal coliform concentrations were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established in 314 CMR 4.00 state that “fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies per 100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies per 100 mL”. Using a yearly arithmetic mean, the standard of 20 colonies per 100 mL was exceeded at fifty-one of fifty-four tributary stations (94%). Only the Quinapoxet River (Mill Street), Rocky Brook (East Branch), and Waushacum (West Waushacum Pond outlet) had an annual mean value less than the standard. Fifteen of the stations had less than 10% of the samples collected containing more than 100 colonies per 100 mL, however, which seems to suggest that mean values may have been elevated by a small percentage of high measurements during 2004. One or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values often increase by several orders of magnitude following storm events or during periods of high groundwater. An alternate way of looking at summary data may give a better representation of actual conditions in these tributaries throughout the year. The use of median values to represent water quality has been used for many years by Environmental Quality staff. Table 3 includes both annual mean and annual median values for fecal coliform data in the tributaries.

Supporting precipitation data from NOAA weather stations in Worcester and Fitchburg and from the USGS station on the Stillwater River in Sterling were used to interpret fecal coliform data by helping segregate water quality samples impacted by storm events from those more representative of baseline conditions. As expected, storm events appear to have a significant impact on fecal coliform concentrations in most tributaries. The importance of precipitation events is illustrated in Tables 4 and 5. These tables also highlight tributaries where conditions are poor even during dry weather. The effect of storm events on both mean and median fecal coliform is addressed, as well as the impact of rainfall as causal agent for the intermittent high concentrations observed in many of the tributaries. Storm events of greater than 0.2 inches that occurred within forty-eight hours of sampling were considered for the purpose of this study, although the majority of the impacts were the result of rainfall within twenty-four hours of sampling.

TABLE 3 (part one of two)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

<u>STATION</u>	<u>MAX</u>	<u>MIN</u>	<u>MEAN</u>	<u>MEDIAN</u> <u>(2004)</u>	<u>MEDIAN</u> <u>(2003)</u>	<u>SAMPLES</u>
Asnebumskit (Mill)	1900	<10	94	30	n/a	46
Asnebumskit (Prin)	4700	<10	421	80	n/a	48
Ball Brook	1360	<10	89	<10	n/a	41
Beaman 2	>2000	<10	214	90	110	43
Beaman 3	>2000	<10	274	70	150	35
Beaman 3.5	>2000	<10	377	175	n/a	26
Boylston Brook	1400	2	136	25	35	46
Chaffins (Malden)	1300	<10	83	20	n/a	46
Chaffins (Poor Farm)	>2000	<10	153	10	n/a	46
Chaffins (Unionville)	420	<10	31	<10	n/a	46
Chaffins (Wachusett)	950	<10	76	25	n/a	46
Cook Brook (Wyoming)	3600	<10	250	30	20	49
East Wachusett (140)	1310	3	71	20	n/a	49
East Wachusett (31)	1260	0	57	<10	n/a	49
East Wachusett (Bull)	870	9	43	10	n/a	49
French Brook (70)	280	5	39	15	20	58
Gates Brook (1)	1600	<10	84	25	20	58
Gates Brook (2)	700	<10	79	30*	40*	51
Gates Brook (3)	1000	<10	76	30*	30*	51
Gates Brook (4)	680	<10	92	50	30*	51
Gates Brook (6)	2300	1	160	50	30*	51
Gates Brook (9)	520	<10	101	55	30	50
Hastings Cove Brook	510	0	38	<10	20	50
Hog Hill Brook	400	<10	36	10*	n/a	46
Houghton Brook	230	<10	41	10*	n/a	49
Jordan Farm Brook	1020	<10	80	<10*	n/a	34
Justice Brook	550	2	32	<10	n/a	49

*below historic levels

TABLE 3 (part two of two)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

<u>STATION</u>	<u>MAX</u>	<u>MIN</u>	<u>MEAN</u>	<u>MEDIAN</u> <u>(2004)</u>	<u>MEDIAN</u> <u>(2003)</u>	<u>SAMPLES</u>
Keyes (Gleason)	600	<10	44	<10*	n/a	49
Keyes (Hobbs)	1510	<10	73	10	n/a	49
Keyes (Onion)	1980	<10	53	<10	n/a	48
Malagasco Brook	1600	8	93	20	40	56
Malden Brook	840	6	81	30	30	58
Muddy Brook	300	0	46	20	20	54
Oakdale Brook	2400	<10	163	50	40	49
Quinapoxet River (CMills)	1500	<10	114	50	10	80
Quinapoxet River (dam)	330	<10	44	20	20	61
Quinapoxet River (Mill St)	160	<10	18	10	n/a	47
Rocky Brook	>2000	<10	87	10	n/a	49
Rocky (E Branch)	34	1	<10	<10	n/a	36
Scanlon Brook	1160	7	75	<10	n/a	47
Scarlett Brook	1140	<10	98	20	n/a	50
Scarlett (Rt12)	840	<10	65	10	n/a	41
Stillwater (62)	1090	<10	113	20	n/a	49
Stillwater River (SB)	900	0	102	40	20	103
Swamp 15 Brook	3600	<10	155	10*	n/a	47
Trout Brook	1900	<10	54	<10	n/a	47
Warren Tannery Brook	800	<10	67	15	n/a	46
Waushacum (Conn)	140	<10	24	<10	n/a	43
Waushacum (filter)	>2000	<10	110	20	n/a	38
Waushacum (Fairbanks)	190	<10	47	20	n/a	49
Waushacum (Pr)	330	<10	29	10*	0	49
Waushacum (WWP)	120	<10	17	<10	n/a	49
West Boylston Brook	>2500	3	156	50	30	58
Wilder Brook	14600	<10	899	25	n/a	22

*below historic levels

Mean fecal coliform concentrations recorded in 2003 were considerably higher than normal due to extremely high maximum values at most stations recorded during storm events in September and October. Storm events during 2004 had a less dramatic though measurable impact on mean fecal coliform concentrations, which were generally within historical norms. No tributary had an annual mean that was higher than previously recorded; five stations recorded their lowest ever value including four on Gates Brook.

Median fecal coliform concentrations in 2004 were mostly comparable to those measured during 2003 and in previous years. Six stations (Gates 2, Hog Hill, Houghton, Jordan Farm, Keyes, and Swamp 15) showed improvement and all recorded their lowest ever annual median, while one station (Gates 9) had declining water quality and its highest ever median coliform concentration. Stations on Beaman Pond Brook continue to exhibit poor water quality although median values were lower than in 2003. Boylston Brook also continues to have below average water quality. Gates 3 had unchanged water quality but with an annual median that equaled last year's record best. The remaining forty-three sampling stations all had median fecal coliform concentrations that were not unusually high or low and did not show any clear historical trends.

Wilder Brook had the highest concentration of fecal coliform when the tributaries were ranked using annual mean values. Asnebumskit (Princeton Street) had the second highest concentration, followed by the three Beaman Brook stations and the station on Cook Brook. Oakdale Brook, Gates 6, West Boylston Brook, and Swamp 15 Brook were also among the worst ten.

The use of median values instead of mean values to assess annual water quality reduces the impact of storm events by suppressing the significance of intermittent extreme concentrations and in doing so often changes tributary rankings. The rankings using the two parameters were not dramatically different this year due in part to reduced impacts by storm events in 2004 but primarily because of the fact that a majority of the streams with the poorest water quality were in fact experiencing constant contamination. The three Beaman Brook stations and Asnebumskit Brook (Princeton Street) remained among the worst when annual median values were used, followed by Gates 9, Oakdale Brook, the Quinapoxet River (Canada Mills), Gates 6, West Boylston Brook, and Gates 4. This suggests that problems at Wilder Brook, Swamp 15 Brook, and Cook Brook were periodic or intermittent, while contamination at the other stations was more regular in nature.

Mean values were strongly impacted by rainfall events as illustrated in Table 4 on the following pages, even though tributary ranking was not greatly affected in 2004 as discussed previously. Annual mean values were significantly reduced (>20%) in most tributaries when all samples collected during or within forty-eight hours of storm events of 0.2 inches or more were excluded. This suggests that these sites were strongly impacted by stormwater pollution. Exclusion of storm samples resulted in minor improvements at two stations (Gates 6, Jordan Farm Brook) and no improvement at seven others. Water quality at Rocky (East Branch), Waushacum (Connelly), and Waushacum (WWP) is quite good, and it appears that stormwater is not having a significant impact. Stormwater effects at Keyes (Onion Patch) are likely mitigated by the pond immediately upstream. Water quality in West Boylston Brook remains poor and it appears that there is a constant source of contamination that masks any stormwater impacts. The two remaining sites (Muddy Brook, Chaffins-Poor Farm) are distant from any potential source of stormwater contamination and do not appear to show obvious impacts.

TABLE 4 (part one of two)

**MEAN AND MEDIAN FECAL COLIFORM – EFFECT OF >0.2” RAINFALL
(colonies/100 mL)**

<u>STATION</u>	<u>MEAN</u> all samples	<u>MEAN</u> no storm samples	<u>MEDIAN</u> all samples	<u>MEDIAN</u> no storm samples
Asnebumskit (Mill)	94	33	30	25
Asnebumskit (Prin)	421	298	80	70
Ball Brook	89	60	<10	<10
Beaman 2	214	137	90	90
Beaman 3	274	182	70	30
Beaman 3.5	377	284	175	100
Boylston Brook	136	99	25	15
Chaffins (Malden)	83	17	20	10
Chaffins (Poor Farm)	153	151*	10	<10
Chaffins (Unionville)	31	13	<10	<10
Chaffins (Wachusett)	76	50	25	20
Cook Brook (Wyoming)	250	143	30	20
East Wachusett (140)	71	29	20	10
East Wachusett (31)	57	24	<10	<10
East Wachusett (Bull)	43	16	10	<10
French Brook (70)	39	21	15	<10
Gates Brook (1)	84	29	25	20
Gates Brook (2)	79	42	30	25
Gates Brook (3)	76	39	30	25
Gates Brook (4)	92	59	50	35
Gates Brook (6)	160	143*	50	30
Gates Brook (9)	101	78	55	40
Hastings Cove Brook	38	27	<10	<10
Hog Hill Brook	36	17	10	<10
Houghton Brook	41	31	10	<10
Jordan Farm Brook	80	64*	<10	<10
Justice Brook	32	<10	<10	<10

*less than 20% improvement

TABLE 4 (part two of two)

**MEAN AND MEDIAN FECAL COLIFORM – EFFECT OF >0.2” RAINFALL
(colonies/100 mL)**

<u>STATION</u>	<u>MEAN</u> all samples	<u>MEAN</u> no storm samples	<u>MEDIAN</u> all samples	<u>MEDIAN</u> no storm samples
Keyes (Gleason)	44	23	<10	<10
Keyes (Hobbs)	73	32	10	<10
Keyes (Onion)	53	62*	<10	<10
Malagasco Brook	93	42	20	10
Malden Brook	81	40	30	20
Muddy Brook	46	47*	20	20
Oakdale Brook	163	108	50	40
Quinapoxet River (CMills)	114	56	50	20
Quinapoxet River (dam)	44	24	20	10
Quinapoxet River (Mill St)	18	13	10	<10
Rocky Brook	87	21	10	<10
Rocky (E Branch)	<10	<10*	<10	<10
Scanlon Brook	75	16	<10	<10
Scarlett Brook	98	42	20	10
Scarlett (Rt12)	65	44	10	<10
Stillwater (62)	113	35	20	10
Stillwater River (SB)	102	74	40	20
Swamp 15 Brook	155	35	10	10
Trout Brook	54	12	<10	<10
Warren Tannery Brook	67	28	15	<10
Waushacum (Conn)	24	24*	<10	<10
Waushacum (filter)	110	48	20	30
Waushacum (Fairbanks)	47	34	20	10
Waushacum (Pr)	29	21	10	<10
Waushacum (WWP)	17	17*	<10	<10
West Boylston Brook	156	166*	50	50
Wilder Brook	899	28	25	<10

*less than 20% improvement

Median fecal coliform concentrations were not strongly affected by rainfall (Table 4). Annual median values did not decline significantly at most stations once samples collected during or within forty-eight hours of storm events of 0.2 inches or more were excluded. Median values help temper the impact of rare storm events on annual statistics, so exclusion of all storm-related samples would not be expected to greatly impact annual median fecal coliform concentrations. There were a few cases where improvements were noted. Two stations on Beaman Pond Brook and the station on Wilder Brook had much lower median values when storm samples were excluded. All three locations had intermittent flow during the year that often only occurred following heavy rain, so it is not unexpected that these stations would show a strong correlation between rainfall and fecal coliform regardless of the type of statistical analysis. Both the Quinapoxet and Stillwater River also showed a significant improvement in annual median fecal coliform concentration when storm samples were removed. The two rivers are major tributaries to the reservoir and integrate conditions found in a large number of smaller streams. Impacts from storm events in the two rivers tend to not be as immediate as they are in smaller tributaries but are often longer lasting.

The percentage of samples exceeding 20 cfu/100mL at each station declines when storm-related samples are removed, but not as much as expected (Table 5). Most stations saw an improvement of less than ten percent, and the largest drop was at Wilder Brook (21%) where storm-related flow makes up a significant portion of annual yield. Most stations unfortunately still have many instances where fecal coliform concentration exceeds 20 cfu/100mL in both dry and wet weather. There are a few stations where removal of storm-related samples actually increased the percentage of samples exceeding the standard; one that has poor water quality regardless of weather (Asnebumskit-Princeton), one with irregular flow (Waushacum-filter beds), and one with good water quality and an upstream pond that filters out pollutants and dampens any storm related impacts (Waushacum-WWP).

An examination of the relationship between storm events and the percentage of samples that exceed 100 cfu/100mL (extremely high concentrations referred to as “spikes”) showed a similar pattern, although a greater number of stations (fourteen) had more than ten percent fewer samples that exceeded the standard when storm-related samples were excluded (Table 5). Many of the fecal coliform “spikes” are the result of storm events, but there remains a number of unexplained intermittent occurrences at most stations as well as a few stations where fecal coliform concentrations in excess of 100 cfu/100mL is the norm rather than the exception.

A matrix was developed for each sampling station that illustrates the relationship between rain events, the timing of these events, and fecal coliform concentrations. These are included with the weekly data in the appendix, and a sample is presented below.

fecal coliform concentration (cfu/100mL)	0-20	21-99	100+
no rainfall w/i 48 hours	22	10	2
0.2 + ” rain w/i 6 hours			1
0.2 + ” rain w/i 6 and w/i 24 hours		1	
0.2 + ” rain w/i 24 hours	1	2	1
0.2 + ” rain w/i 24 and w/i 48 hours		1	
0.2 + ” rain w/i 48 hours	3	1	5

TABLE 5 (part one of two)

FECAL COLIFORM SPIKES – EFFECT OF >0.2” RAINFALL

<u>STATION</u>	<u>% > 20cfu</u> all samples	<u>% > 20cfu</u> no storm samples	<u>% > 100cfu</u> all samples	<u>% > 100cfu</u> no storm samples
Asnebumskit (Mill)	57	50	17	6
Asnebumskit (Prin)	75	76	48	47
Ball Brook	29	23	15	6
Beaman 2	70	66	47	46
Beaman 3	69	59	40	26
Beaman 3.5	81	72	58	50
Boylston Brook	50	44	33	24
Chaffins (Malden)	39	19	13	0
Chaffins (Poor Farm)	41	38	22	16
Chaffins (Unionville)	15	6	7	3
Chaffins (Wachusett)	50	47	15	13
Cook Brook (Wyoming)	53	43	22	15
East Wachusett (140)	39	34	8	5
East Wachusett (31)	18	11	8	5
East Wachusett (Bull)	27	16	8	3
French Brook (70)	38	21	14	5
Gates Brook (1)	50	37	19	5
Gates Brook (2)	53	50	25	13
Gates Brook (3)	55	50	20	8
Gates Brook (4)	65	61	27	18
Gates Brook (6)	65	58	31	21
Gates Brook (9)	66	63	30	18
Hastings Cove Brook	22	14	12	5
Hog Hill Brook	30	16	11	3
Houghton Brook	43	37	12	5
Jordan Farm Brook	29	26	18	11
Justice Brook	8	3	6	0

TABLE 5 (part two of two)

FECAL COLIFORM SPIKES – EFFECT OF >0.2” RAINFALL

<u>STATION</u>	<u>% > 20cfu</u> all samples	<u>% > 20cfu</u> no storm samples	<u>% > 100cfu</u> all samples	<u>% > 100cfu</u> no storm samples
Keyes (Gleason)	29	21	12	5
Keyes (Hobbs)	37	29	14	8
Keyes (Onion)	17	8	2	3
Malagasco Brook	46	41	21	11
Malden Brook	53	45	19	8
Muddy Brook	41	35	15	16
Oakdale Brook	65	60	37	33
Quinapoxet River (CMills)	58	49	35	20
Quinapoxet River (dam)	44	33	13	2
Quinapoxet River (Mill St)	21	15	2	0
Rocky Brook	16	8	8	5
Rocky (E Branch)	3	3	0	0
Scanlon Brook	28	19	11	0
Scarlett Brook	48	39	20	12
Scarlett (Rt12)	41	36	20	15
Stillwater (62)	45	34	18	5
Stillwater River (SB)	55	46	27	18
Swamp 15 Brook	43	28	30	13
Trout Brook	19	15	2	0
Warren Tannery Brook	39	28	11	3
Waushacum (Conn)	28	28	7	3
Waushacum (filter)	47	53	16	15
Waushacum (Fairbanks)	49	45	18	17
Waushacum (Pr)	31	25	4	3
Waushacum (WWP)	16	18	4	3
West Boylston Brook	66	63	31	26
Wilder Brook	50	29	27	7

Results from 2004 clearly show the negative impacts of storm events on many tributaries, but additional sampling is necessary to refine our understanding of these impacts. In some streams the negative impacts appear to occur immediately after an event, while in others the impacts are delayed. The duration of negative impacts also appears to be variable, and seasonal effects may also have a role on water quality changes. Stormwater sampling will be done in 2005 to gather additional data from both large and small tributaries, and samples will be collected for several days following each storm to document temporal changes in fecal coliform concentrations. Stormwater sampling done by university students over the past few years will also be interpreted to help provide additional information on the timing and duration of storm-related impacts.

Some initial interpretation of seasonal effects has been attempted using 2004 data. Table 6 on the following page helps to illustrate seasonal differences both in the prevalence of samples with high fecal coliform concentrations as well as with their apparent dependence upon storm events. The samples have been grouped into three month periods to help show seasonal effects. Table 6 lists the number of samples that exceeded 20 and 100 colonies per 100mL, and also the number of these samples that were associated with a storm event of 0.2" or more. A final set of three columns contains the percentage of samples that exceeded 100 colonies per 100mL during the spring, summer, and fall. No exceedences during the winter were associated with a storm.

Significant seasonal differences are obvious in the table. A total of 689 samples were collected during the three month winter period (January-March) and only 16 (2%) contained more than 100 colonies per 100mL while only 94 (14%) contained more than 20 colonies per 100mL. A single sample collected from Muddy Brook in early January was the only one with elevated levels of fecal coliform associated with a rain event. Both rain events and high fecal coliform concentrations are very uncommon during this time of year.

The 719 samples collected during the spring (April-June) included 172 (24%) that contained more than 100 colonies per 100mL and 403 (56%) that contained more than 20 per 100mL. More than half of the samples (52%) containing more than 100 colonies per 100mL were linked to rain events of 0.2" or more, while 43% of samples with more than 20 colonies per 100mL were collected within 48 hours of a storm event.

Summer samples (July-September) had an even higher percentage with elevated fecal coliform concentrations, with 244 of 640 (38%) containing more than 100 colonies per 100mL and 464 (73%) containing more than 20 colonies per 100mL. A total of 61% of the samples with more than 100 colonies per 100mL were associated with rain events; 44% of samples with more than 20 colonies per 100mL were storm related samples.

Samples collected between October and December included 40 of 602 (7%) with more than 100 colonies per 100mL and 148 (25%) with more than 20 colonies per 100mL. Nearly half (45%) of the samples with more than 100 colonies per 100mL were collected during or after rain events as were 41% of the samples containing more than 20 colonies per 100mL.

It is clear that spring samples included a much higher percentage of both 'spikes' (>100) and moderately elevated (>20) samples than seen in the winter. Summer samples had an even higher percentage, while fall samples were generally of better quality. The percentage of 'spikes' that appear related to rainfall follows a similar pattern, while percentage of samples with moderately elevated fecal coliform remains relatively constant throughout much of the year (see Table 7).

TABLE 6

SEASONAL DIFFERENCES - HIGH FECAL COLIFORM AND STORM EVENTS

	Jan-March				April-June				July-Sept				Oct-Dec				Sp %>100 rain	Su	Fall
	>100	>100wet	>20	>20wet	>100	>100wet	>20	>20wet	>100	>100wet	>20	>20wet	>100	>100wet	>20	>20wet			
Asnebumskit (Mill)	1	0	5	0	2	1	9	2	3	3	8	5	0	0	2	2	50	100	
Asnebumskit (Prin)	0	0	6	0	7	1	10	3	13	6	13	6	3	0	7	1	14	46	0
Ball Brook	1	0	1	0	1	0	6	1	4	4	5	4	0	0	0	0	0	100	
Beaman 2	3	0	7	0	7	2	11	5	6	1	6	1	4	1	6	1	29	17	25
Beaman 3	0	0	4	0	7	4	10	5	3	1	4	1	4	1	6	1	57	33	25
Beaman 3.5	0	0	1	0	8	4	9	4	4	1	5	1	3	1	6	2	50	25	33
Boylston Brook	0	0	3	0	4	2	7	3	8	3	10	4	1	0	3	1	50	38	0
Chaffins (Malden)	0	0	0	0	2	2	8	4	4	4	7	5	0	0	3	3	100	100	
Chaffins (Poor Farm)	0	0	1	0	4	1	5	1	5	4	10	5	1	0	3	1	25	80	0
Chaffins (Unionville)	0	0	0	0	2	1	5	3	1	1	2	2	0	0	0	0	50	100	
Chaffins (Wachusett)	0	0	3	0	5	2	9	3	2	1	9	4	0	0	2	1	40	50	
Cook Brook (Wyoming)	0	0	1	0	5	3	9	5	4	3	10	4	2	1	6	2	60	75	50
East Wachusett (140)	1	0	3	0	0	0	4	1	2	2	8	4	1	0	4	1	100	0	
East Wachusett (31)	0	0	0	0	0	0	4	2	4	2	5	3	0	0	0	0	50		
East Wachusett (Bull)	0	0	0	0	2	1	4	2	2	2	6	3	0	0	3	2	50	100	
French Brook (70)	0	0	0	0	7	5	15	9	0	0	6	4	0	0	1	1	71		
Gates Brook (1)	1	0	4	0	4	4	11	7	5	4	9	5	0	0	5	3	100	80	
Gates Brook (2)	1	0	2	0	3	2	8	2	6	5	12	5	3	1	4	1	67	83	33
Gates Brook (3)	0	0	2	0	3	2	10	3	5	4	12	5	2	1	4	1	67	80	50
Gates Brook (4)	1	0	4	0	2	2	10	3	8	4	13	5	3	1	6	2	100	50	33
Gates Brook (6)	0	0	3	0	5	2	10	3	9	5	12	5	2	1	8	3	40	56	50
Gates Brook (9)	2	0	5	0	5	2	12	3	7	5	13	5	1	1	3	1	40	71	100
Hastings Cove Brook	0	0	0	0	0	0	2	1	6	4	7	4	0	0	2	1	67		
Hog Hill Brook	0	0	0	0	2	2	4	3	3	9	6	0	0	0	1	1	100	100	
Houghton Brook	0	0	1	0	1	0	7	2	5	4	13	5	0	0	0	0	0	80	
Jordan Farm Brook	0	0	1	0	3	2	5	2	2	1	2	1	1	1	2	1	67	50	100
Justice Brook	0	0	0	0	0	0	0	0	2	2	4	3	0	0	0	0	100		
Keyes (Gleason)	0	0	0	0	2	2	5	3	4	3	9	4	0	0	0	0	100	75	
Keyes (Hobbs)	0	0	0	0	2	2	6	2	5	3	9	4	0	0	1	0	100	60	
Keyes (Onion)	0	0	0	0	0	0	3	3	1	0	4	2	0	0	0	0		0	
Malagasco Brook	0	0	1	0	3	2	11	5	8	5	11	5	0	0	3	1	67	63	
Malden Brook	0	0	2	0	7	5	12	7	3	2	12	5	0	0	5	2	71	67	
Muddy Brook	0	0	3	1	1	0	6	3	7	2	13	5	0	0	0	0	0	29	
Oakdale Brook	1	0	4	0	7	2	12	5	9	2	13	2	1	1	3	1	29	22	100
Quinapoxet River (CMills)	0	0	1	0	10	5	14	7	15	10	23	11	1	1	6	3	50	67	100
Quinapoxet River (dam)	0	0	5	0	4	4	11	6	2	2	7	5	0	0	3	2	100	100	
Quinapoxet River (Mill St)	0	0	0	0	0	0	4	3	1	1	6	3	0	0	0	0	100		
Rocky (E Branch)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		50	
Rocky Brook	0	0	0	0	0	0	2	1	4	2	6	4	0	0	0	0		100	
Scanlon Brook	0	0	0	0	0	0	3	1	4	4	10	5	0	0	0	0		33	
Scarlett (Rt12)	1	0	2	0	4	2	6	3	3	1	6	1	0	0	3	1	50	50	100
Scarlett Brook	1	0	3	0	4	2	8	4	4	2	10	2	1	1	3	2	33	83	
Stillwater (62)	0	0	2	0	3	1	11	4	6	5	8	5	0	0	1	0	40	56	
Stillwater River (SB)	0	0	1	0	10	4	25	10	16	9	25	10	0	0	6	3	71	83	100
Swamp 15 Brook	0	0	0	0	7	5	8	5	6	5	10	5	1	1	2	2		100	
Trout Brook	0	0	1	0	0	0	2	0	1	1	5	4	0	0	1	0	100		
Warren Tannery Brook	0	0	1	0	3	3	5	4	2	2	8	4	0	0	4	2	0	100	
Washacum (Conn)	0	0	0	0	2	0	4	1	0	0	5	0	0	0	2	1	0	33	
Washacum (Fairbanks)	1	0	3	0	3	0	7	1	3	1	13	2	0	0	1	0		50	
Washacum (filter)	0	0	1	0	3	1	6	2	1	1	6	2	0	0	5	1	33	100	
Washacum (Pr)	0	0	1	0	0	0	7	3	2	1	5	1	0	0	2	1		50	
Washacum (WWP)	0	0	0	0	0	0	2	0	2	1	6	1	0	0	0	0		50	
West Boylston Brook	1	0	5	0	4	2	13	6	10	4	12	4	3	2	7	3	50	40	67
Wilder Brook	0	0	1	0	2	1	5	3	2	2	2	2	2	2	3	2	50	100	100
TOTAL (elevated)	16	0	94	1	172	90	403	174	244	150	464	203	40	18	148	60	52	61	45

TABLE 7

SEASONAL HIGH FECAL COLIFORM – effect of rain events

	<u>WINTER</u>	<u>SPRING</u>	<u>SUMMER</u>	<u>FALL</u>
total samples collected	689	719	640	602
% samples > 20 col/100mL	14%	56%	73%	25%
% samples > 100 col/100mL	2%	24%	38%	7%
total ‘elevated’ samples collected	94	403	464	148
% samples > 20 col/100mL “rain linked”	1%	43%	44%	41%
% samples > 100 col/100mL “rain linked”	0%	52%	61%	45%

There appears to be an obvious relationship between elevated fecal coliform concentrations and season, with most contaminated samples collected during the spring and summer. It is also clear that the percentage of samples containing more than 100 colonies per 100mL that appear to be the result of rain events follows a similar seasonal pattern. In three of the four seasons, however, the percentage of samples that contain more than 20 colonies per 100mL is relatively constant (41%-44%) and probably not related to the season, and in fact the primary reason that this is not true for the winter as well is likely due to the fact that there was only a single rain event during the winter of 2004. During 2003 there were three storms during the winter and 20% of the samples collected during this period contained more than 20 fecal coliform colonies per 100mL. A total of 44% percent of these samples with elevated concentrations were linked to storm events. It seems very clear that 55-60% of the samples that contain more than 20 colonies per 100mL are not due to storm events regardless of the time of year.

Not all streams appear to be impacted equally by rain events, nor do they all vary seasonally in similar fashion. Of the thirteen stations that had less than 10% of samples with more than 100 colonies per 100mL, only four appeared to have a strong relationship between elevated fecal coliform and rain events. Eleven stations had 30% or more samples with more than 100 colonies per 100mL, but only one of these (Swamp 15 Brook) appeared to have a strong correlation between elevated concentrations and rainfall. Three of the stations (Asnebumskit at Princeton Street, Beaman 2, and Oakdale Brook) had no correlation between elevated concentrations and rainfall, with no more than 30% of the high values measured during or after a storm event. These three streams seem to have a fairly constant source of fecal coliform contamination that is not the result of storm events.

A number of stations appear to show a strong link between fecal coliform contamination and rain events. There are a total of fifteen stations at which 75% or more of samples collected throughout the year that contained more than 100 colonies per 100mL appear to be the result of a storm of 0.2” or more. Most contain low to moderate levels of contamination. Seven stations show only a very weak correlation, with less than 30% of the ‘high coliform’ samples related to a rain event. Summary statistics for most stations are included in Table 8 on the following page.

TABLE 8

INDIVIDUAL TRIBUTARIES – effect of rain events on high fecal coliform

STATION NAME	samples > 100	% > 100	% linked to rain
Chaffins (Malden)	6	13	100
Hog Hill Brook	5	11	100
Justice Brook	2	6	100
Quinapoxet River (dam)	6	13	100
Quinapoxet River (Mill St)	1	2	100
Scanlon Brook	4	11	100
Trout Brook	1	2	100
Warren Tannery Brook	5	11	100
Gates Brook (1)	9	19	89
Keyes (Gleason)	6	12	83
Wilder Brook	6	27	83
Asnebumskit (Mill)	5	17	80
Ball Brook	5	15	80
Swamp 15 Brook	14	30	79
East Wachusett (Bull)	4	8	75
French Brook (70)	7	14	71
Gates Brook (3)	10	20	70
Malden Brook	10	19	70
Chaffins (Unionville)	3	7	67
East Wachusett (140)	3	8	67
Gates Brook (2)	12	25	67
Stillwater (62)	9	18	67
Cook Brook (Wyoming)	11	22	64
Malagasco Brook	11	21	64
Gates Brook (9)	13	30	62
Quinapoxet River (CMills)	26	35	62
Scarlett Brook	9	20	56
Gates Brook (4)	13	27	54
East Wachusett (31)	4	8	50
Gates Brook (6)	16	31	50
Rocky Brook	4	8	50
Stillwater River (SB)	26	27	50
Washacum (Pr)	2	4	50
Washacum (WWP)	2	4	50
West Boylston Brook	17	31	47
Beaman 3	14	40	43
Chaffins (Wachusett)	7	15	43
Beaman 3.5	15	58	40
Boylston Brook	13	33	38
Asnebumskit (Prin)	23	48	30
Oakdale Brook	17	37	29
Muddy Brook	8	15	25
Beaman 2	17	47	24
Washacum (Fairbanks)	6	18	17
Keyes (Onion)	1	2	0
Washacum (Conn)	2	7	0
Rocky (E Branch)	0	0	n/a

Water quality does not follow the same seasonal pattern in every stream. Most tributaries exhibit their poorest water quality during the summer months (July-September), but seven stations had significantly worse water quality during the spring (April-June). Two stations on Beaman Pond Brook and one on Waushacum Brook had fewer samples with elevated concentrations in the summer due in part to a reduced overall number of summer samples caused by low flow conditions. A station on French Brook had seven samples containing more than 100 colonies per 100mL during the spring but none during the remainder of the year, likely due to the presence of beaver. Stream flow during the spring is significant; during the remainder of the year much of the flow is restricted by the dam. The beaver are an obvious source of bacteria. The remaining three stations that did not follow the common pattern are not as easy to explain. Malden Brook, Chaffin Brook (Wachusett), and the Quinapoxet River (dam) all had twice as many samples with high concentrations of fecal coliform from the spring as from the summer. Quinapoxet ‘spikes’ were all linked to rain events, but this was not the case for the other two stations.

Multiple sampling stations on Gates Brook have been utilized for many years to try and locate sources of fecal contamination. Gates Brook was historically one of the most contaminated tributaries in the watershed, although water quality has improved as an increasing number of homes are connected to the new municipal sewers. Annual median fecal coliform concentrations at Gates 2 and Gates 3 during 2004 were the lowest ever recorded, and all stations except Gates 9 had annual median concentrations below the average of values measured over the past ten years. A total of 912 homes, apartments, and businesses have been connected to the West Boylston sewer system in the past six years, many within the Gates Brook subbasin. Even so, water quality in Gates Brook is still poor and specific sources of contamination remain largely undetected, although some clear patterns are beginning to emerge. Regardless of whether annual mean or annual median was used, stations close to the tributary sources were more contaminated than stations close to the reservoir. Gates 6 and Gates 9 had the highest annual mean and highest annual median respectively, and both had a high percentage of samples exceeding 20 colonies and 100 colonies per 100mL (Table 9). Water quality at Gates 4 was only marginally better, but improved water quality was noted at Gates 3 and Gates 2. The station closest to the reservoir (Gates 1) had the best water quality regardless of the statistic used. If influence of storm events is removed from the statistical analysis (eliminating all samples collected within 48 hours of a storm event of 0.2” or greater) there is very little change; Gates 6 and Gates 9 are still the most contaminated stations during dry weather and Gates 1 consistently has the best water quality.

TABLE 9

FECAL COLIFORM – GATES BROOK STATIONS
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	%>20	%>100
Gates 1	1600	<10	84	25	50	19
Gates 2	700	<10	79	30	53	25
Gates 3	1000	<10	76	30	55	20
Gates 4	680	<10	92	50	65	27
Gates 6	2300	<10	160	50	65	31
Gates 9	520	<10	101	55	66	30

Additional analysis of sewer connections and their relationship to water quality is now possible with the recent acquisition of georeferenced connection data from the two sewer towns. Holden and West Boylston regularly provide updated information and a GIS datalayer is being created that will allow both visual and statistical views of sewer parcels and changes over time, which hopefully can then be linked to positive changes in water quality.

Samples were collected from three stations on Beaman Pond Brook to continue an investigation of water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations. Water samples were collected during both dry and wet conditions. Monthly samples were also collected from two stations on Gates Brook to provide baseline data for a UMASS stormwater monitoring project, and an additional eighteen stormwater samples from these stations were analyzed at the DCR lab facility in John Augustus Hall in West Boylston.

Data from Beaman Pond Brook were collected from Station #2 (downstream of houses), Station #3 (downstream of pond), and Station #3½ (downstream of horses) and are summarized in Table 10. Data from 2003 highlighted poor water quality at the station downstream of a property with horses. No management practices were being used by the owners to keep manure out of the brook. It is clear from the 2004 data that activities on this property continue to contaminate Beaman Pond Brook. All fecal coliform metrics identify Station #3½ as having the poorest water quality. This is true regardless of whether all samples are used or if only dry weather samples are included. Efforts continue to attempt to bring the owners into compliance with existing regulations.

TABLE 10

FECAL COLIFORM – BEAMAN POND BROOK STATIONS
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	%>20	%>100
Beaman Pond #2	>2000	<10	214	90	70	47
Beaman Pond #3	>2000	<10	274	70	69	40
Beaman Pond #3½	>2000	<10	377	175	81	58

Monthly samples were collected from two stations on Gates Brook to provide baseline data for a University of Massachusetts stormwater monitoring project. Samples collected during dry weather usually contained low concentrations of fecal coliform, but concentrations were elevated in some dry weather samples collected during the spring, summer, and fall. One storm event (duration of nineteen hours) was sampled by university students and staff during 2004, and eighteen stormwater samples were filtered, incubated, and counted at the DCR lab facility in West Boylston. Data are included in Table 11 on the following page and seem to indicate that water quality at the agricultural station is similar to water quality at the urban station. This is a change from 2003 when urban water quality was poor compared to the agricultural site. Samples for nutrients, alternative indicator organisms, and the protozoa *Giardia* and *Cryptosporidium* were also collected during the storm event. A complete write-up of the study will be available from the University of Massachusetts.

TABLE 11

FECAL COLIFORM – GATES BROOK STATIONS (UMASS)
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	%>20	%>100
GBBR (urban) – monthly	280	<10	64	20	44	22
GBWD (agriculture) – monthly	160	<10	60	40	67	22
GBBR (urban) – storm	340	70	178	200	100	55
GBWD (agriculture) – storm	470	110	202	170	100	100

Samples collected monthly during 2003 at the urban station (GBBR) had much poorer water quality than did those collected from the agricultural station (GBWD). Samples collected during the first four storms of 2003 from GBBR were also much worse than the samples collected from GBWD, but samples collected in fall 2003 and from the 2004 storm in April presented a different picture, as did the monthly 2004 samples. It appears that connections to the municipal sewer system in the urbanized section of the Gates Brook subbasin have resulted in improved water quality in that area. Improvements to water quality in the agricultural section of the subbasin were also noted, but that could be the result of sewer connections as well since there are a number of homes adjacent to the tributary in both areas.

Fecal coliform samples have been collected from stations on Cook Brook for the past six years to evaluate the impacts of sewerage on water quality. Cook Brook flows through the Pinecroft neighborhood of West Boylston and Holden, an area known for numerous problems with outdated or inadequate septic systems. A decision was made in the late 1990s to replace the septic systems with a municipal sewer system. Fecal coliform data were collected in 1998 prior to sewer construction, and weekly data collection has continued since then. A large number of homes have been connected to sewers in this neighborhood during the past six years. Initial results seem to show improvements to water quality as a result of the new sewers, with both then annual median fecal coliform concentration and the percentage of samples that exceed 20 colonies per 100mL having declined since sewers were installed and homes were connected. A more detailed analysis will be done using GIS which will allow the comparison between newly sewerage parcels and water quality changes over time.

Additional samples are collected from tributaries when fecal coliform concentrations are abnormally high and there is no obvious cause. A sample collected from West Boylston Brook on March 8th contained more than 2500 fecal coliform per 100mL, so samples were collected from the same station and from two upstream locations the following day. The sample collected at Route 12 was found to contain high amounts of fecal coliform, but no source was identified and concentrations were back to normal the following week. Elevated concentrations were noted again at the same station in early 2005 and more sampling was done upstream with mixed results. A more detailed investigation is planned for the spring and summer of 2005.

Elevated fecal coliform concentrations at all six Gates Brook stations were noted for the first time in 2004 on March 22nd. Samples from Beaman Pond Brook (#2) and Scarlett Brook also contained high levels of fecal coliform on the following day, while all other stations had excellent water quality. All eight stations were resampled on March 24th. Most samples contained very little fecal coliform, although Gates 9 and Beaman Pond #2 were still elevated. Concentrations declined the following week, although both stations did have relatively poor water quality throughout the spring and summer.

Asnebumskit Brook at Princeton Street had elevated fecal coliform counts (>150) beginning in mid May. A sample collected on July 9th contained 2000 colonies per 100mL and an extra sample was collected four days later to see if concentrations were continuing to climb. Fecal coliform counts remained high throughout the remainder of the summer and did not drop below 100 colonies per 100mL until mid October. Staff made an initial investigation but did not determine a source.

Additional samples were also collected during and following three storm events in 2004. Samples were collected from some or all of eight stations with flow information available. Data compiled are preliminary and will be examined in detail once additional data are collected during 2005.

Historical data were examined to detect any long-term water quality trends. As described earlier, fecal coliform concentrations in 2004 were mostly comparable to those measured during 2003 and in previous years. Six stations (Gates 2, Hog Hill, Houghton, Jordan Farm, Keyes, and Swamp 15) showed improvement and all recorded their lowest ever annual median, while one station (Gates 9) had declining water quality and its highest ever median coliform concentration. Stations on Beaman Pond Brook continue to exhibit poor water quality although median values were lower than in 2003. Boylston Brook also continues to have below average water quality and remediation efforts to remove the identified source of contamination have not yet begun. Gates 3 had unchanged water quality but with an annual median that equaled the previous best. The remaining forty-three sampling stations all had median fecal coliform concentrations that were not unusually high or low and did not show any clear historical trends.

3.2 NUTRIENTS

Samples for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, UV-254, and total organic carbon were collected in May, October, and December from nine tributary stations and analyzed at the MWRA Deer Island Lab using methods with low detection limits. Unfortunately no samples were collected in August, and no December data appear to exist for nitrate-nitrogen, nitrite-nitrogen, ammonia, or total phosphorus from seven of the nine stations. December data are available from French and Malagasco Brooks and for the remaining parameters. Monthly samples (April-December, none in August) for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc and then frozen; samples for total phosphorus were frozen without filtration. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements at these stations were determined each week using staff gages and USGS rating curves. All data are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries ranged from 0.032 mg/L NO₃-N to 3.37 mg/L NO₃-N. Nitrate levels are usually highest in Gates and West Boylston Brooks and significantly elevated with respect to the other tributaries and the reservoir. This was true once again in 2004, although concentrations in Gates Brook were much lower than in the previous year and only slightly more than half of what was reported from West Boylston Brook. It appears that concentrations reported for 2003 may have been artificially high due to the fact that only two samples were collected during the year, although sampling at that same frequency in 2004 did not appear to produce abnormal results. Highly elevated concentrations of nitrates in Gates Brook during 2003 could also have been the result of a leak in the municipal sewer system as documented within the 2003 annual water quality report. Elevated nitrate levels in both Gates and West Boylston Brooks are expected because of the high number of improperly functioning septic systems and the density of residential and commercial development in these subbasins. A drop in nitrate-nitrogen concentration should begin to occur once a majority of homes in the subbasin are connected to the municipal sewer system. A greater sampling frequency might be necessary to detect short-term or long-term trends, however, since seasonal or weather-related fluctuations in nitrate concentrations could strongly impact summary statistics of a small data set. For this same reason, no attempt will be made to comment on trends at most of the stations other than to state that most measured values fell within historical norms. Samples were collected more frequently at the Quinapoxet and Stillwater Rivers, and annual mean nitrate concentration in the Stillwater was the lowest ever recorded. Nitrate concentrations in the Quinapoxet River were low but within previously recorded ranges.

TABLE 12

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.274	1.10	0.084	1.81	3.37	0.519	0.405	0.205
MIN	0.032	0.328	0.066	1.49	2.48	0.417	0.237	0.066
MEAN	0.113	0.737					0.311	0.133

Samples were collected as part of an ongoing study to evaluate the impacts of sewerage on water quality in a small urbanized tributary (Cook Brook). Concentrations are usually higher in Cook Brook than in any of the routine tributaries sampled during the year, with an annual mean concentration more than double than what is found in Gates or West Boylston Brooks. The Cook Brook subbasin has recently been sewerage and improvements to water quality are expected, although not apparent at this time. Additional samples collected more frequently will hopefully document positive changes to annual nitrate-nitrogen concentrations. Samples were also collected from two similar sized subbasins with different land uses for comparison purposes. Concentrations in Jordan Farm Brook (agriculture) and in Rocky Brook (undeveloped) were significantly lower than in Cook Brook (dense residential).

TABLE 13

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	Jordan Farm	Rocky (East Branch)
YEAR	2000	2001	2002	2003	2004	2004	2004
MAX	5.82	4.59	4.63	4.78	4.46	1.41	0.012
MIN	2.18	1.98	4.39	1.90	1.71	1.25	0.009

Nitrite-nitrogen was detected at very low concentrations, with a maximum recorded value of 0.012 mg/L measured in December at French Brook. Nearly half of the thirty-four samples and all of the tributaries contained detectable concentrations of nitrite-nitrogen (>0.005 mg/L). The previous year this was true for less than ten percent of the samples and in only three of the tributaries. Ammonia was detected in most tributaries during the year at concentrations similar to those seen in 2003. The maximum recorded value in 2004 was 0.140 mg/L measured in French Brook during May (Table 14). French Brook had the highest recorded concentration during 2003 as well, possibly due to the presence of beaver immediately upstream of the sampling location. Concentrations in a number of the other tributaries were lower than in 2003, while others were higher or remained the same. It should again be pointed out that interpretation of annual data using only two or three data points must be done cautiously.

TABLE 14

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

station	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK	J.FARM	ROCKY (EB)
MAX	0.140	0.045	0.054	0.005	0.023	0.037	0.026	0.024	0.007	0.009	<0.005
MIN	0.053	0.017	0.038	<0.005	0.009	<0.005	<0.005	0.007	<0.005	<0.005	<0.005
MEAN	0.085	0.031					0.014	0.016			

Phosphorus is an important nutrient, and has been determined to be the limiting factor controlling algal productivity in the Wachusett Reservoir. EPA Water Quality Criteria (1976) recommended a maximum concentration of 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving waterbodies. Concentrations measured in the eight routine Wachusett tributaries during 2004 ranged from 0.006 mg/L to 0.065 mg/L total P. Concentrations were comparable to those seen last year and remained lower than in previous years at most stations, although no definitive conclusions should be drawn due to the limited number of samples collected. Only two of twenty-eight samples collected (one from French Brook in May and one from the Stillwater River in April) exceeded the recommended maximum concentration.

TABLE 15

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.055	0.049	0.029	0.0216	0.020	0.036	0.047	0.065
MIN	0.012	0.017	0.019	0.0216	0.016	0.027	0.006	0.017
MEAN	0.033	0.033					0.024	0.036

Data from Cook Brook in the Pinecroft neighborhood (Table 16) appear to show improvements to water quality as a result of the new sewers. Total phosphorus data were collected in 1998 prior to sewer construction, and a maximum value of 4.74 mg/L was recorded. Maximum values have not exceeded 0.2 mg/L since that time, and declined annually until 2003. The maximum value of 0.081 mg/L in 2004 appears to be an anomaly; the sample was collected within six hours of a rain event of 0.28" and contained very high concentrations of fecal coliform as well as the high concentration of total phosphorus. The value reflects the impacts of contaminated stormwater rather than an annual elevated condition or any long-term negative trend.

Total phosphorus samples were also collected from two similar sized subbasins with different land uses for comparison purposes. Concentrations in Jordan Farm Brook (agriculture) and in Rocky Brook (undeveloped) were significantly lower than in Cook Brook (dense residential).

TABLE 16

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	COOK (Wyoming)	Jordan Farm	Rocky (East Branch)
YEAR	2000	2001	2002	2003	2004	2004	2004
MAX	0.095	0.053	0.031	0.033	0.081	0.043	0.015
MIN	0.008	0.012	0.021	0.009	0.031	0.016	0.011

Silica concentrations ranged from a low of 2.94 mg/L in May (French Brook) to a high of 11.3 mg/L in October (Malden Brook). The annual mean concentration in the watershed during 2004 was 7.92 mg/L, slightly higher than the annual mean in 2002 and 2003. The annual mean concentration was highest in Malden Brook; the lowest annual mean concentrations were in French Brook, the Quinapoxet River, and the Stillwater River.

Total suspended solids are those particles suspended in a water sample retained by a filter of 2µm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in Wachusett tributaries ranged from <5.0 mg/L to 25.5 mg/L, with thirty-three of forty-one samples containing less than the detection limit. High suspended solids were measured during May and October in Malden Brook, during October in Cook Brook, and during May, June, September, and October in the Stillwater River.

Total organic carbon (TOC) and UV-254 measure organic constituents in water and are important as a way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.69 to 34.5 mg/L, with an overall mean value of 5.84 mg/L. These data are similar though slightly higher than comparable measurements done during 2003. The highest readings were again recorded from Malagasco Brook and French Brook, and the lowest from Gates Brook and West Boylston Brook. Measurements of UV-254 were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were also from Malagasco and French Brooks.

Concentrations of twenty-one metals were measured in monthly samples (April-December) that were collected from the Stillwater and Quinapoxet Rivers. No antimony, beryllium, cadmium, selenium, silver, or thallium were detected in any samples, while arsenic, chromium, copper, lead, mercury, nickel, and zinc were present but at very low concentrations (less than 10 µg/L). Barium was present in slightly higher concentrations but never higher than 25 µg/L. Aluminum, calcium, iron, magnesium, manganese, potassium, and sodium were present at higher concentrations (see Table 17), but within the range of concentrations recorded during 2002 and 2003. The only significant difference between the two rivers continues to be in the amount of sodium present; concentrations in the Quinapoxet were nearly fifty percent higher than the concentration measured in the Stillwater and likely reflect the greater degree of development and elevated amounts of road salt used in the Quinapoxet River subbasin. There were slight increases in all seven parameters in Stillwater River samples collected in 2004; an ongoing study of the Stillwater River District will investigate sources of these contaminants.

TABLE 17

METALS CONCENTRATIONS (mg/L) – annual mean and range

station	Al	Ca	Fe	Mg	Mn	K	Na
QUINAPOXET	0.11	7.80	0.42	1.45	0.09	1.74	26.2
range	0.18 - 0.06	8.64 - 6.41	0.753 - 0.19	1.59 - 1.15	0.29 - 0.03	2.23 - 1.23	30.2 - 18.7
STILLWATER	0.19	7.17	0.70	1.28	0.14	1.46	18.6
range	0.59 - 0.06	10.8 - 5.34	1.88 - 0.23	1.92 - 1.01	0.35 - 0.05	1.94 - 1.02	23.9 - 14.3

3.3 SPECIFIC CONDUCTANCE

Fresh water systems almost always contain small to moderate amounts of mineral salts in solution. Specific conductance is a measure of the ability of water to carry an electric current, which is dependent on the concentration and availability of these ions. Elevated conductivity levels are indicative of contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

Specific conductance was measured weekly at all stations with a low of 34 $\mu\text{mhos/cm}$ in October at Rocky Brook (East Branch) and a high of $>3000 \mu\text{mhos/cm}$ in March at Gates 2 (Route 140). Annual mean ranged from a low of 55 $\mu\text{mhos/cm}$ (Justice Brook) to a high of 970 $\mu\text{mhos/cm}$ (Gates 6 at Lombard Avenue). The highest values were seen during winter and spring and were related to snow and ice storms, salt applications, and elevated runoff. Conductivity values were also higher in many tributaries during the summer, fall, and early winter when flows were low.

Annual values in most tributaries were again lower than the previous year, although differences were small. Two tributaries that have been sampled on a regular basis for many years had their highest annual median values ever. French Brook and the Stillwater River had elevated specific conductance measurements due to reduced flow caused by active beaver populations. A number of other tributaries that have not been monitored for a number of years also recorded their highest ever annual specific conductance, but this was probably the result of not having any recent data using the current equipment rather than any actual decline in water quality.

Criteria were proposed by the DWM during the mid 1990s relating specific conductance and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedence of specific criteria. Tributaries with more than fifty percent of the samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100mL are potentially impacted by septic systems. Impacts are considered minor if less than eighty percent of samples exceed a specific conductance standard of 120 $\mu\text{mhos/cm}$, moderate if greater than eighty percent of samples exceed the 120 $\mu\text{mhos/cm}$ standard, and severe if more than twenty percent of samples exceed a standard of 360 $\mu\text{mhos/cm}$. These criteria appear to give a fairly good indication of whether or not a sampling location is impacted by failing septic systems rather than by an alternative source of contamination, although annual flow conditions need to be considered. It is important to note that changes in sampling equipment have led to overall increases in specific conductance throughout the watershed and these criteria may need to be updated. The use of fifty percent exceedence as an indicator of potential impact by septic systems should also be used with caution, since rain events and periods of reduced flow have a significant impact on fecal coliform concentrations and the timing of sampling during the year could easily change overall results. Stream flow appears to be directly related to conductivity, with “dry” years (low flows) concentrating contaminants during the warm months and elevating mean annual conductivity. Years with less precipitation and lower tributary flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason multiple years should be used in assessing these criteria.

An assessment of specific conductance and fecal coliform data from 2004 using the criteria described above suggests that sixteen of fifty-four stations (30%) were likely contaminated by improperly functioning septic systems. All three stations on Beaman Pond Brook, five of six stations on Gates Brook, and stations on Cook, Oakdale, and West Boylston Brook were considered severely impaired. Problems along Cook, Oakdale, Gates, and West Boylston Brook have been well documented, and sewers have recently been constructed specifically to deal with this issue. Beaman Pond Brook has problems believed to be related to horses rather than septic systems; elevated conductivity in this instance may be the result of road salt rather than septic impacts.

Water quality in the middle reaches of the Quinapoxet River reflects inputs from a number of tributaries impacted by septic systems. The sampling station at Canada Mills showed moderate impacts from septic systems, while both the upper end of the river (Mill Street) and the mouth (dam) were unimpacted. Both Asnebumskit Brook stations also showed moderate impacts from septic systems, as did Malden Brook. These two tributaries have exhibited poor water quality in the past with septic system impacts suggested. The Stillwater River continues to exhibit minor impacts from septic systems, likely the result of upstream contributions from its tributaries. The Stillwater River watershed is currently being studied in detail with an Environmental Quality Assessment Report to be published during 2005.

A multi-year examination (1998 through 2004) of this assessment shows conditions initially improving and then stabilizing in the watershed. Nearly fifty percent of the stations assessed in 1998 were deemed likely contaminated by faulty septic systems. This declined to thirty-eight percent in 1999, thirty-three percent in 2000, and thirty percent in 2001 and in 2002. Poor conditions in 2003, when more than fifty percent of the stations appeared contaminated by septic systems, were due to the addition of several problem stations and the dropping of two locations with good water quality. A large number of tributaries were assessed in 2004 to provide a better overall picture of water quality in the Wachusett watershed, and the percentage of stations likely contaminated by septic systems declined to thirty percent. Continued improvement is possible, with reductions in fecal coliform concentrations and specific conductance over the next few years as many of the remaining homes with outdated or failing septic systems are connected to new municipal sewers in West Boylston and Holden.

3.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution's acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH have been done in the tributaries for a number of years. More than a decade of routine sampling in the tributaries had shown very little variation either seasonally or over time. Historic low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.5 *GIARDIA* / *CRYPTOSPORIDIUM*

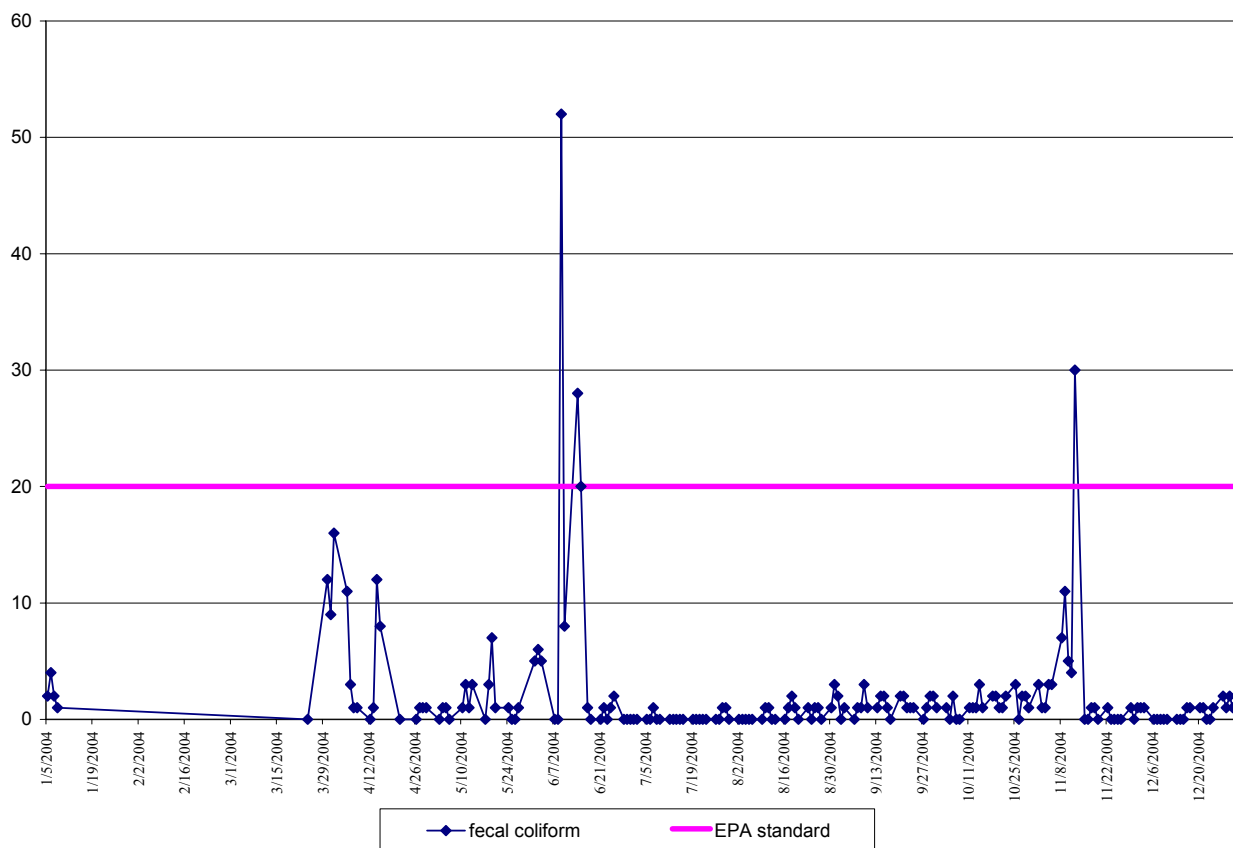
Giardia and *Cryptosporidium* samples were not collected by Environmental Quality staff during 2004 and no additional sampling is planned for the future. Data have been collected from a variety of locations in previous years, but no clear seasonal trends were determined and presence or absence appears to be related more to precipitation, flow conditions, and presence of wildlife rather than season.

4.0 RESULTS OF RESERVOIR MONITORING PROGRAM

4.1 BACTERIA

A total of 188 bacteria samples were collected at the Cosgrove Intake by a combination of DCR and MWRA staff during 2004. All of the DCR samples were surface grabs collected Monday through Thursday from the back walkway or from a boat in close proximity to the intake. MWRA official compliance samples are taken Monday through Friday from an internal tap. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100mL. More than ninety-eight percent of the samples collected at the Cosgrove Intake during 2004 contained less than the standard (Figure 3). The standard was exceeded only three times, on June 9th, on June 14th, and on November 12th. Problems caused by roosting gulls and other waterfowl were minimized due to a rigorous harassment program, but the exceedence in November was definitely related to bird activity. It is unclear what caused the elevated concentrations in June.

FIGURE 3
COSGROVE INTAKE
FECAL COLIFORM CONCENTRATIONS (colonies/100mL)



Bacterial transect samples were collected from twenty-three surface stations across the reservoir to document the relationship between seasonal bacteria variations and visiting populations of gulls, ducks, and geese. Data were also used to judge the effectiveness of bird harassment activities. Sample locations were illustrated on Figure 2. Samples were collected monthly from July through October and twice monthly in November and December. All fecal coliform transect data are included in Table 18 below.

TABLE 18
FECAL COLIFORM TRANSECT DATA (colonies/mL)
Wachusett Reservoir - 2004

SITE	July 28	Aug 25	Sept 16	Oct 14	Nov 10	Nov 24	Dec 13	Dec 22
A-3	0	0	12	0	7	0	0	0
B-2	0	0	4	0	4	1	1	0
B-3	1	0	9	1	3	2	1	0
C-1	1	0	5	4	5	5	0	3
C-3	0	0	1	0	10	1	0	0
C-5	1	0	4	1	0	1	1	1
D-1	0	0	2	4	26	3	7	4
D-2	0	3	0	3	16	1	2	3
D-4	3	0	1	0	4	2	0	0
E-2	0	1	6	9	68	6	8	3
E-4	1	0	1	0	16	4	2	1
F-2	2	0	87	1	4	5	13	16
F-3	1	0	8	5	9	3	4	2
F-4	0	0	5	0	0	0	2	1
G-2	3	0	8	1	3	6	23	33
H-2	1	3	0	1	3	13	32	35
I-2	1	0	0	4	3	32	52	13
J-2	6	1	4	1	9	6	14	36
J-3	0	0	15	3	29	14	53	70
J-4	1	1	74	28	81	137	188	115
K-2	3	0	0	0	25	36	177	173
M-1	19	1	2	0	21	7	43	92
N-1	2	0	0	1	28	40	59	82

No stations north of the narrows (the ‘bird-free’ zone) contained more than twelve fecal coliform colonies per 100mL during July, August, September, and October. Elevated concentrations were noted south of the narrows, especially in areas where the birds are permitted to roost, beginning in September and peaking during November and December. Several stations north of the narrows did contain elevated fecal coliform concentrations in early November, but harassment activities were increased and concentrations declined.

4.2 WATER COLUMN CHARACTERISTICS

4.2.1 FIELD PROCEDURE

DCR staff routinely measure water column profiles in the Wachusett Reservoir for the following parameters: temperature, dissolved oxygen, percent oxygen saturation, specific conductance, and hydrogen ion activity (pH). Profiles are measured weekly at Station 3417 (Basin North) in conjunction with plankton monitoring (see Section 4.4) and quarterly at the other key monitoring stations (Station 3412/Basin South and Thomas Basin; see Figure 1) weather and ice conditions permitting.

The thermally stratified water column of summer is characterized by a layer of warm, less dense water occupying the top of the water column (“epilimnion”), a middle stratum characterized by a thermal gradient (“metalimnion”), and a stratum of cold, dense water at the bottom (“hypolimnion”). Profile measurement during the period of thermal stratification is important for many reasons including the following: (1) to monitor phytoplankton growth conditions and detect “blooms” of potential taste and odor causing organisms associated with discrete strata of the water column (see Section 4.4), (2) to track the progress of the Quabbin “interflow” through the Wachusett basin during periods of water transfer (see below), and (3) to monitor water quality within each stratum and determine appropriate depths for vertically stratified nutrient sampling. Profiles are measured at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Water column profiles are measured with a “Reporter” or “H20” multiprobe and “Surveyor 3” water quality logging system manufactured by Hydrolab Corporation (now a component of the Hach Company located in Loveland, Colorado). These instruments are routinely charged and calibrated during the field season. At the conclusion of field work, data recorded by the logging system is downloaded to a PC as an Excel spreadsheet.

Station 3417 (Basin North) has been selected for graphically depicting seasonal changes in the water column profile of Wachusett Reservoir because it is representative of the deepest portion of the basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

4.2.2 THE QUABBIN “INTERFLOW” IN WACHUSETT RESERVOIR

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 2002, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 94 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. The interflow penetrates through the main basin of Wachusett Reservoir (from Route 12 Bridge to Cosgrove Intake) in about 3 to 4 weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a “short circuit” undergoing minimal mixing with ambient Wachusett Reservoir water.

A sustained transfer was initiated on May 19th and continued through November 8th with one interruption on September 3rd. After the sustained transfer ended, intermittent transfers continued through December 27th.

A significant deflection in the conductivity profile to lower values was detected at Station 3417 (Basin North) on June 18th (see Specific Conductance section below) indicating completion of interflow penetration through the main basin to Cosgrove Intake in a period of about 31 days from transfer initiation. This penetration interval was slower by about 5 days than predicted according to regression analysis of data from previous years and is likely due to the relatively early date of transfer initiation (see Worden and Pistrang, 2003).

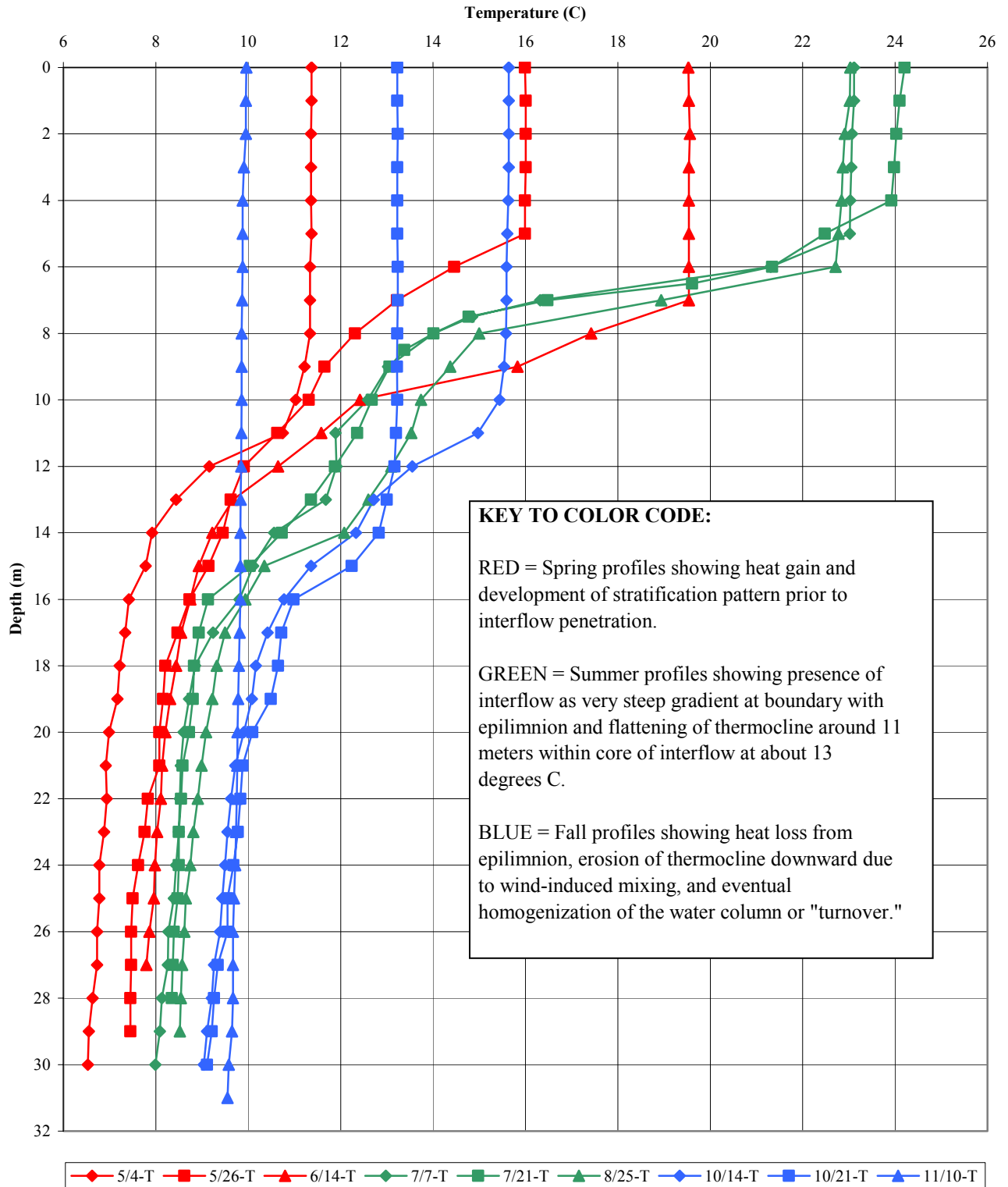
By late-August, the interflow stratum had developed into its usual configuration with a thickness of nine meters forming between 6 and 15 meters deep. At the conclusion of 2004, the transfer volume totaled 222 million cubic meters, equivalent to 89 percent of the Wachusett basin volume. The influence of the 2004 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

4.2.3 TEMPERATURE

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover at Station 3417 (Basin North) is depicted in Figure 4 on the following page.

An early stage of thermal stratification was evident on the May 4th measurement date when a difference of approximately 4° C existed between the top and bottom of the water column. The top of the water column continued to gain heat and a fairly uniform gradient from 19.5° C at the surface extending down to around 10° C at a depth of 14 meters is evident on June 14th.

Figure 4
2004 Profiles of Temperature at Station 3417 (Basin North)



The establishment of the interflow from Quabbin (see section 4.2.2 above) can be seen in the profile measured on August 25th. A very steep thermal gradient exists between depths of six and eight meters in which the temperature dropped approximately 8° C. This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between depths of approximately 6 and 15 meters.

The presence of the Quabbin interflow was also evident in the temperature profiles as a pronounced flattening or plateau in the thermocline between 10 and 13 meters where the temperature centers around 13° C. This plateau represents the “core” of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

Highest temperatures in the epilimnion were recorded in July at about 24° C while temperatures in the hypolimnion remained at about 9° C throughout the summer. In late August, the system began to lose heat as radiation intensities diminished and air temperatures cooled.

The profile measured on October 14th shows that heat losses and wind energy had eroded the thermocline downward into the metalimnetic interflow and mixed it with the epilimnion down to a depth of 11 meters. By October 21st, the water column was mixed down to a depth of 14 meters thus homogenizing the epilimnion and most of the remaining metalimnetic interflow stratum.

Wind energy and heat loss eventually dispersed the remnant hypolimnion and mixed the entire water column, in an event known as fall “turnover.” The water column was shown to be essentially isothermal at around 10° C in a profile recorded on November 10th.

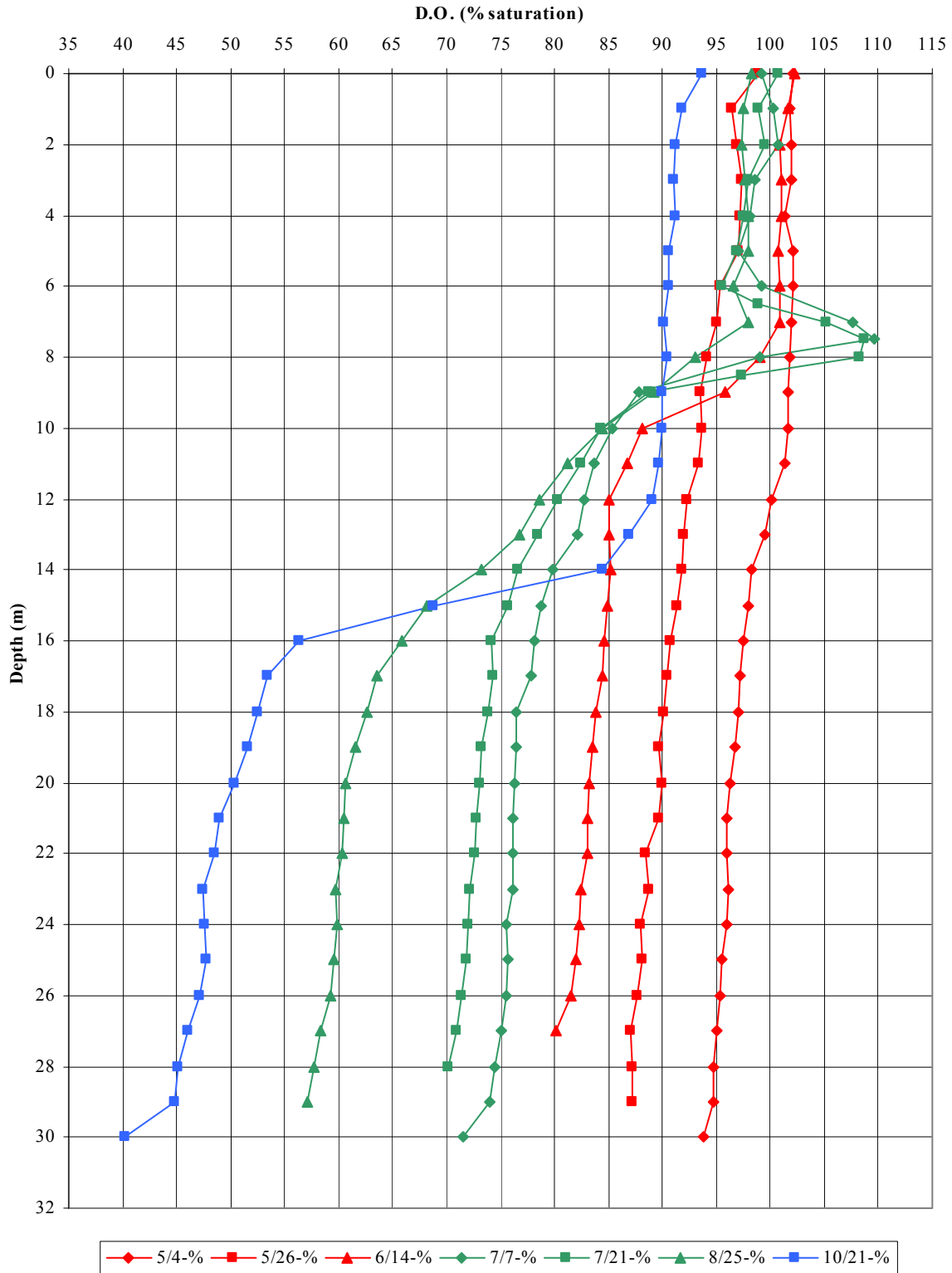
4.2.4 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout most of the year generally show values ranging from 60 to 100 percent saturation for ambient water temperatures. Saturation values in the epilimnion remained above 90 percent throughout the year, whereas saturation values in the metalimnion and hypolimnion from May through October fall progressively lower (Figure 5).

Maximum dissolved oxygen saturation values ranging up to 109.6% were observed from July 7th to August 23rd associated with the remarkable 2004 metalimnetic bloom of *Chrysosphaerella* (see section 4.4). This persistent spike in dissolved oxygen concentrations at a depth of around 7.5 meters resulted from photosynthetic activity by billions of *Chrysosphaerella* colonies aggregated within a narrow stratum of the water column as shown in the profiles measured on July 7th and July 21st.

During the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to between 45 and 55 percent saturation before fall turnover in early November replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in most of the metalimnion during the stratification period (bloom stratum excepted), but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen demand by microbial decomposition processes occurring at the sediment-water interface.

Figure 5
2004 Profiles of Dissolved Oxygen Percent Saturation at Station 3417 (Basin North)



The profile measured on October 21st shows homogenization of the water column down to 14 meters with the concomitant replenishment of oxygen to around 90 percent saturation throughout the mixed volume. In early November, wind energy dispersed the remnant stratification pattern mixing and exposing the entire basin volume to the atmosphere thereby replenishing dissolved oxygen concentrations to above 90 percent saturation at all depths.

4.2.5 SPECIFIC CONDUCTANCE

Specific conductance (“conductivity”) profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 $\mu\text{S}/\text{cm}$ with an average value between 125 and 150 $\mu\text{S}/\text{cm}$. In contrast, the average conductivity value of Quabbin water is approximately 40 $\mu\text{S}/\text{cm}$. Typically, during periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin range from 75 to 125 $\mu\text{S}/\text{cm}$ depending on the amount of water received from Quabbin. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity. Figure 6 (see following page) depicts conductivity profiles measured at Station 3417 (Basin North) from June through October.

On June 14th, before the Quabbin transfer had penetrated to Station 3417, conductivity values ranged between 117 and 126 $\mu\text{S}/\text{cm}$ throughout the water column. The profiles recorded on July 7th and July 21st show the development of the interflow stratum as a “trough” in the conductivity profile between depths of around 6 and 16 meters. This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. By August 25th, a minimum interflow conductivity value of about 73 $\mu\text{S}/\text{cm}$ was observed at a depth of 9 meters at Station 3417.

Profiles measured on October 21st show that heat losses and wind energy had caused the water column to be mixed down to a depth of 14 meters thus homogenizing the epilimnion and most of the metalimnetic interflow stratum. The conductivity of this mixed portion of the water column was about 100 $\mu\text{S}/\text{cm}$. In early November, wind energy dispersed the remnant stratification pattern causing conductivity in the entire water column to register around 96 $\mu\text{S}/\text{cm}$.

4.2.6 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate “buffering system”). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration. Generally, pH values in Wachusett Reservoir range from around neutral (pH=7) to slightly acidic (pH=6). Figure 7 depicts pH profiles measured at Station 3417 (Basin North) from June through October.

Figure 6
2004 Profiles of Specific Conductivity at Station 3417 (Basin North)

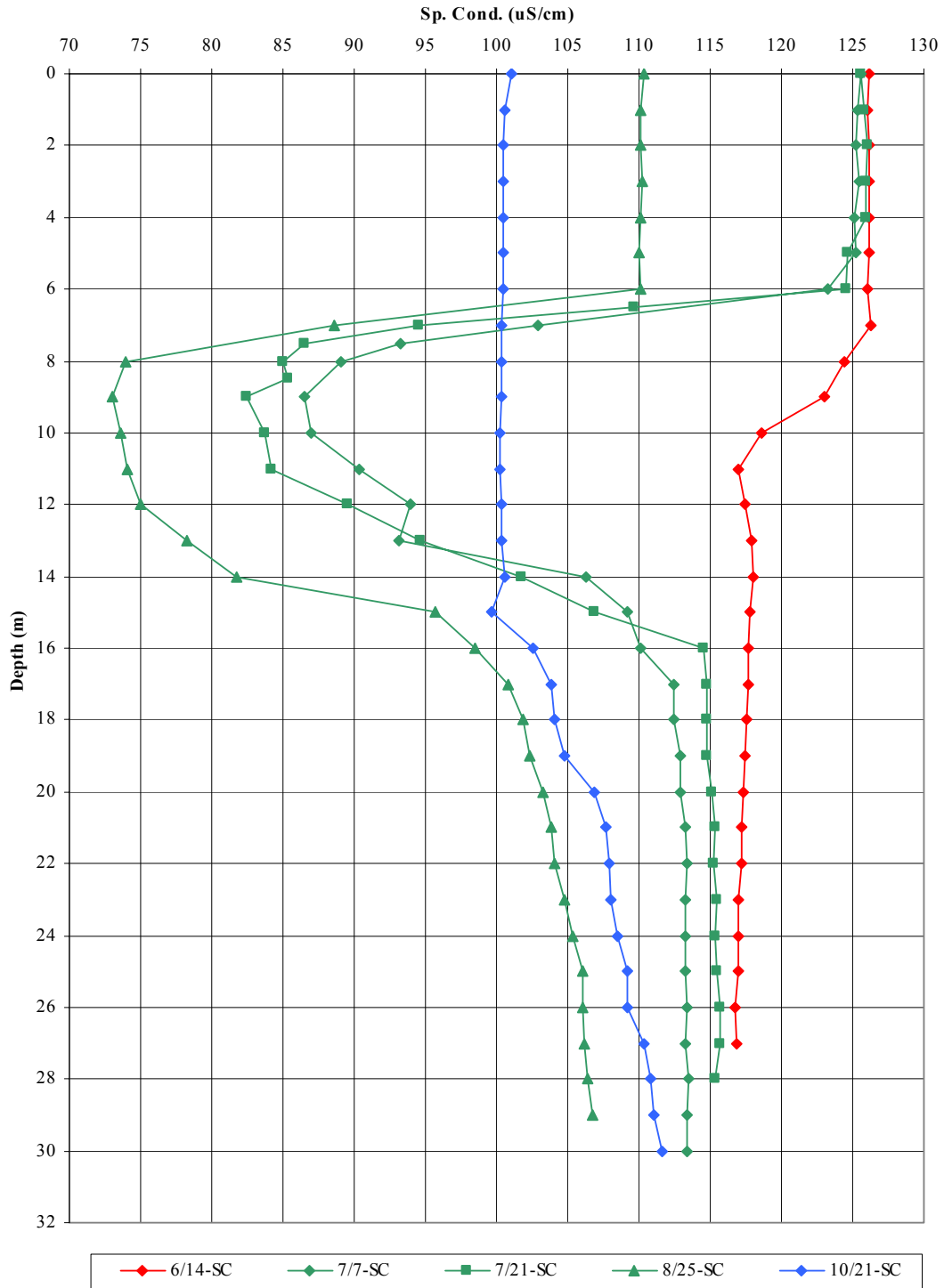
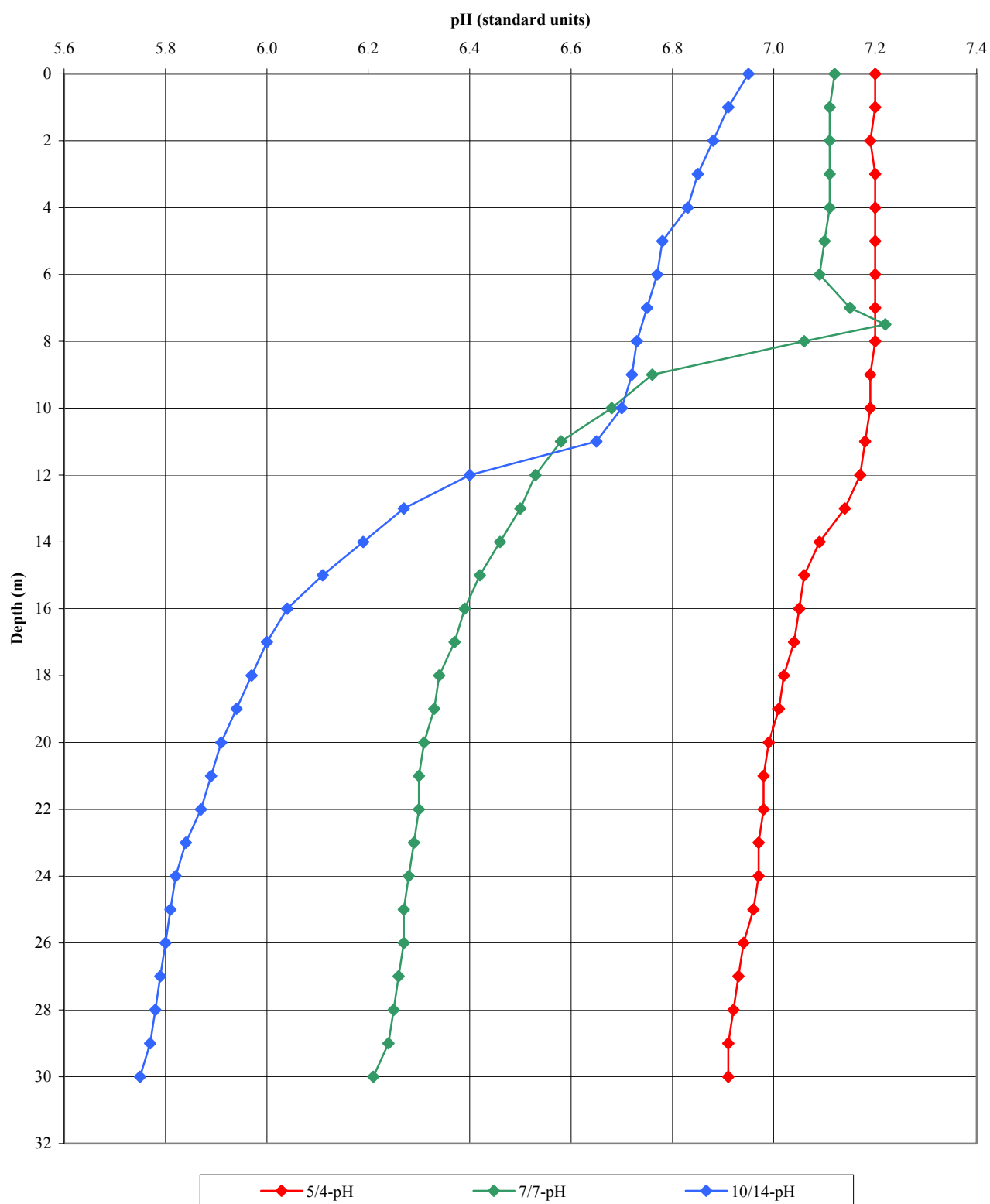


Figure 7
2004 Profiles of Hydrogen Ion Activity (pH) at Station 3417 (Basin North)



Photosynthesis by phytoplankton results in the uptake of carbon dioxide dissolved in the water. The uptake of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. On July 7th, maximum pH values spiked briefly over 7.2 in a narrow stratum around 7.5 meters deep as a consequence of the remarkable 2004 metalimnetic bloom of *Chrysosphaerella* (see Section 4.4).

Values of pH ranging from 6.2 to 6.8 were measured in the metalimnion during most of the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir.

In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. Hypolimnetic pH values had decreased to values around 5.8 as shown by the profile measured on October 14th.

The profile measured on October 14th also shows that heat losses and wind energy had eroded the thermocline downward into the metalimnetic interflow and mixed it with the epilimnion down to a depth of 11 meters. Resulting pH values in the homogenized portion of the water column registered around 6.8. Complete mixing associated with “turnover” in November resulted in nearly uniform pH values throughout the water column.

4.3 NUTRIENTS

4.3.1 FIELD PROCEDURE

Sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted quarterly since the conclusion of the program of monthly sampling conducted from October 1998 to September 1999. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (July), near the end of the stratification period (October), and during a winter period of mixis before ice cover (December). Samples were collected at three of the main monitoring stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in the recent comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003). Modifications to the quarterly sampling program have consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.05

mg/L from previous limits of 0.2 and 0.6 mg/L) and the addition of UV254 absorbance (in 2000) and dissolved silica (in 2004) among the parameters to be measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as a relative assay of the concentrations of organic compounds dissolved in the water. Samples to be analyzed for dissolved silica are field filtered (0.45µm membrane) and these measurements complement conventional silica analyses that have been conducted since the beginning of the sampling program.

4.3.2 RESULTS OF NUTRIENT ANALYSES

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2003 is used as a basis for interpreting data generated in 2004. Results of quarterly nutrient sampling in 2004 document concentrations and intensities that register almost entirely within historical ranges (see Table 19 on the following page as well as the Appendix).

Patterns of nutrient distribution in quarterly samples correspond closely to those documented in the recent comprehensive report (Worden and Pistrang, 2003). These patterns consist of: (1) prominent seasonal and vertical variations with low epilimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter, and (2) interannual fluctuations in nutrient concentrations and parameter intensities occurring across the main basin as a result of the divergent influences of the Quabbin transfer and the Wachusett watershed with temporary lateral gradients becoming pronounced for nitrate, silica, UV254, and conductivity, either increasing or decreasing downgradient of Thomas Basin depending on the dominant influence.

Preliminary results for dissolved silica in comparison to conventional silica analyses (“total acid-extractable”) indicate that generally 85% to 98% of silica present in Wachusett Reservoir was in the dissolved form during most of the year. However, results from samples collected in July show that “particulate” silica was the dominant form comprising 47% to 86% of silica present. The nature of this “particulate” silica, its sources, and its transformational relationship with dissolved silica are the subject of ongoing research. Future nutrient sampling at Wachusett Reservoir is planned to continue on the quarterly schedule.

4.4 PHYTOPLANKTON

4.4.1 FIELD PROCEDURES

Sampling from a boat at Station 3417 (Basin North) during the late April – early November thermal stratification period has been a key element of phytoplankton monitoring since 2003 when new staff assignments and procedures were implemented. Boat sampling replaced the previous method of collecting grabs at various depths from the catwalk at the rear of Cosgrove Intake. Station 3417 (Basin North) is representative of the deepest portion of the basin and it is not influenced by seiche effects or turbulence from water withdrawals which can destabilize stratification boundaries and obscure associated phytoplankton growth patterns at Cosgrove Intake. However, samples collected at Cosgrove are adequately representative of the main basin during the late November – early April period of mixis when the water column is homogenous, so sampling is conducted from the catwalk during this period ice conditions permitting.

Table 19 - Wachusett Reservoir Nutrient Concentrations:

Comparison of Ranges from 1998-03 Database⁽¹⁾ to Results from 2004 Quarterly Sampling⁽²⁾

Sampling Station ⁽³⁾	Ammonia (NH ₃ ; ug/L)		Nitrate (NO ₃ ; ug/L)		Silica (SiO ₂ ; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	<u>1998-03</u>	<u>Quarterly'04</u>	<u>1998-03</u>	<u>Quarterly'04</u>	<u>1998-03</u>	<u>Quarterly'04</u>	<u>1998-03</u>	<u>Quarterly'04</u>	<u>2000-03</u>	<u>Quarterly'04</u>
Basin North/3417 (E)	<5 - 12	<5 - 12	<5 - 159	26 - 146	0.59 - 3.02	1.61 - 3.27	<5 - 13	5 - 11	0.032 - 0.072	0.045 - 0.071
Basin North/3417 (M)	<5 - 36	<5 - 12	<5 - 164	26 - 148	0.77 - 3.31	1.57 - 3.30	<5 - 17	8 - 9	0.032 - 0.079	0.046 - 0.074
Basin North/3417 (H)	<5 - 41	<5 - 31	48 - 202	70 - 168	1.27 - 3.92	2.06 - 3.72	<5 - 14	6 - 11	0.032 - 0.069	0.047 - 0.072
Basin South/3412 (E)	<5 - 14	<5 - 11	<5 - 172	30 - 161	0.56 - 3.84	1.68 - 3.52	<5 - 17	6 - 11	0.031 - 0.085	0.048 - 0.081
Basin South/3412 (M)	<5 - 39	<5 - 14	11 - 184	50 - 164	0.95 - 4.03	1.84 - 3.48	<5 - 22	8 - 12	0.032 - 0.089	0.045 - 0.085
Basin South/3412 (H)	<5 - 44	<5 - 38	49 - 224	86 - 169	1.64 - 4.13	2.95 - 3.72	<5 - 37	8 - 12	0.036 - 0.091	0.055 - 0.079
Thomas Basin (E)	<5 - 18	<5 - 15	<5 - 201	51 - 158	0.62 - 5.00	1.78 - 3.86	<5 - 23	8 - 15	0.026 - 0.143	0.058 - 0.153
Thomas Basin (M)	<5 - 27	8 - 15	<5 - 205	37 - 163	0.88 - 4.94	1.74 - 3.91	<5 - 22	9 - 13	0.026 - 0.150	0.037 - 0.155
Thomas Basin (H)	<5 - 24	11 - 57	<5 - 236	34 - 178	0.92 - 4.99	1.73 - 4.23	<5 - 24	8 - 14	0.027 - 0.200	0.034 - 0.156

- Notes: (1) 1998-03 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through December 2003, except for measurement of UV254 initiated in 2000 quarterly sampling
(2) 2004 quarterly sampling conducted May, July, October, and December
(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

Sampling frequency is generally weekly in early spring, fall, and winter increasing to twice a week (usually Monday and Thursday) during the period from May through September when episodes of rapid population growth (“blooms”) by problematic “taste and odor” organisms commonly occur. Samples are usually collected at two depths which vary slightly between periods of mixis and stratification. During periods of mixis, samples are collected: (1) near the top of the water column at a depth of three meters and (2) at a depth of eight meters which corresponds to the upper intake depth at the Cosgrove Intake. During the annual stratification period samples are collected: (1) near the middle of the epilimnion at a depth of three meters and (2) near the bottom of the epilimnion at a depth of six meters. Samples are collected using a Van Dorn Bottle and returned to the laboratory for concentration and microscopic analysis (details given below in next section).

In addition to grab sampling, routine phytoplankton monitoring during the stratification period also includes measurement of hydrographic parameters such as temperature, dissolved oxygen, hydrogen ion activity (pH), and specific conductance with a Hydrolab multiprobe. These parameters are measured at one meter intervals as the multiprobe is lowered from the surface to record a profile of the entire water column. Secchi transparency is also recorded as an approximate measure of particulate matter (mostly plankton) suspended in the water column.

During the stratification period, when spikes in dissolved oxygen concentrations in profile measurements (a “positive heterograde curve”) indicate photosynthetic activity associated with a phytoplankton bloom within a specific stratum of the water column, an additional grab sample is collected at that depth to identify and quantify the bloom organism. Chrysophytes (“golden-brown algae”) such as *Chrysosphaerella*, *Dinobryon*, and *Synura* are generally responsible for subsurface blooms in Wachusett Reservoir and the “bloom stratum” that they prefer generally coincides with the steep temperature gradient at the interface between the epilimnion and the metalimnetic interflow (Worden and Pistrang, 2003).

Productivity by phytoplankton during the stratification period is almost exclusively restricted to the epilimnion and its boundary with the metalimnetic interflow (generally no deeper than eight meters). The absence of photosynthetic activity below the epilimnion/interflow boundary has been documented consistently since 1987 by multiprobe measurements of water column profiles. Steadily declining concentrations of dissolved oxygen below this boundary over the weeks of the stratification period indicate that microbial decomposition of sedimenting organic matter is the dominant biological activity. It is likely that the steep temperature and density gradients at this boundary prohibit inoculation and/or dispersion of photosynthetic organisms into the metalimnetic interflow.

4.4.2 LABORATORY CONCENTRATION AND MICROSCOPIC ANALYSIS OF PLANKTON

Prompt acquisition of information on phytoplankton densities is critical for agency decision-making on the need for algaecide applications to avoid taste and odor problems. The method of sand filtration for concentration of phytoplankton samples has long been in use by both MWRA and DCR because it enables relatively rapid analysis of samples while subjecting organisms to minimal damage or distortion. The specific method used is documented in Standard Methods

Twelfth Edition (1965, pages 669-671; photocopies kindly provided by Warren Zepp of MWRA). The method entails gravity filtration of sample water placed in a funnel through a layer of fine sand followed by washing and gentle shaking of the sand with waste filtrate water in a beaker to detach organisms from the sand grains, and lastly, prompt decanting of the concentrated sample after the sand has been allowed to settle. A portion of the concentrated sample is then analyzed microscopically using quantitative techniques as presented below.

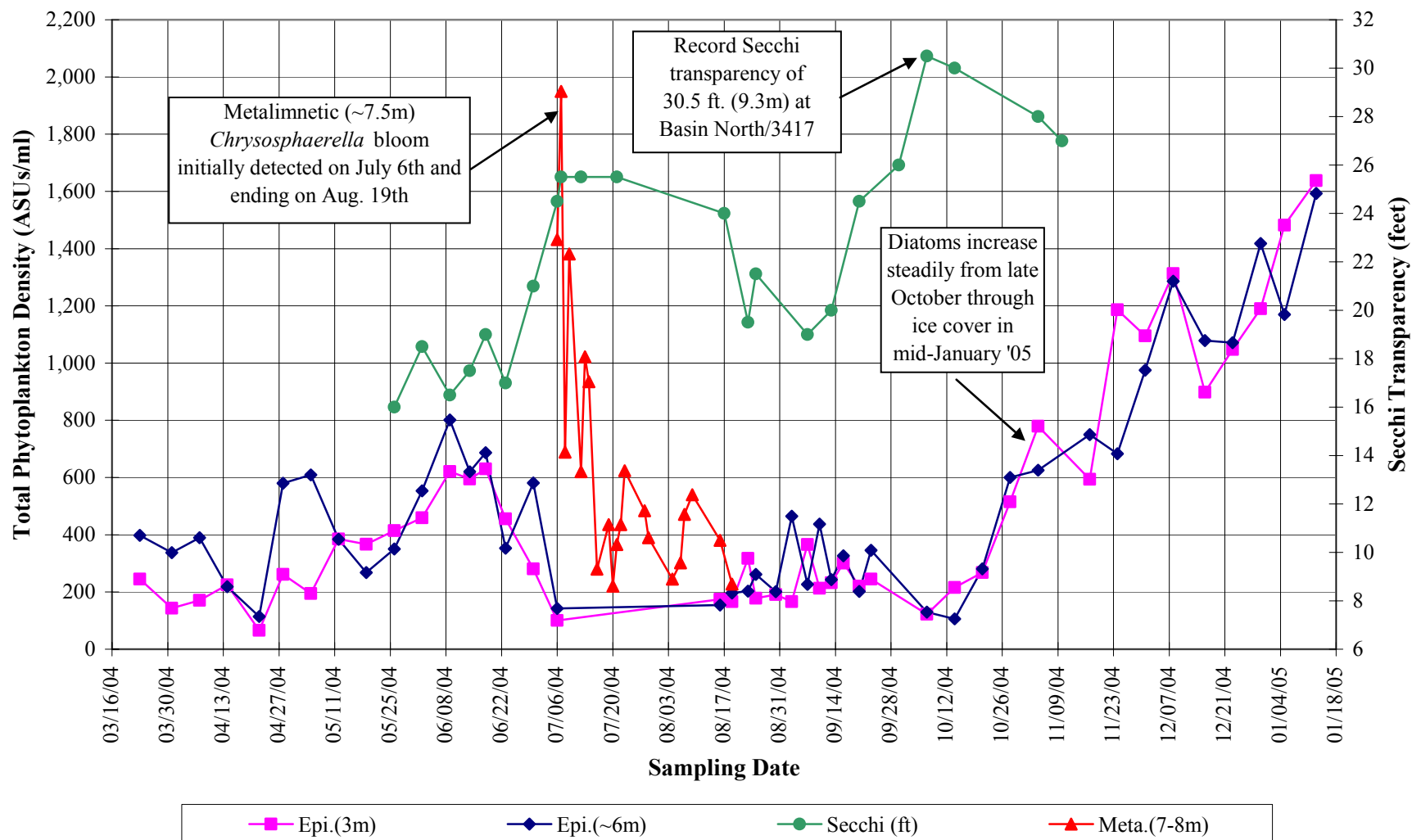
Phytoplankton taxa in concentrated samples are enumerated using a Sedgewick-Rafter (S-R) Cell which enables phytoplankton densities to be quantified. Each concentrated sample is mixed to homogenize the sample and then 1 ml of the sample is withdrawn with a pipette and placed into the S-R Cell. Initial inspection of phytoplankton within the S-R Cell is accomplished with a stereozoom dissecting microscope capable of magnification from 7 to 45 times. Use of this instrument to scan the entire S-R Cell is important to detect colonies of certain motile taxa present at low densities such as *Synura* and/or colonies floating against the underside of the coverslip such as *Anabaena*.

Scanning of the entire S-R cell enables colonial “taste and odor” organisms to be detected and quantified at very low densities. Colonies observed in the S-R Cell using the stereozoom dissecting microscope are quantified by counting the number of colonies and then measuring their average diameter using a compound microscope (see below). This information, along with the known concentration factor arising from sand filtration, is used to calculate and express densities of colonial “taste and odor” organisms as Areal Standard Units (see below).

After the scanning procedure described above, microscopic analysis of phytoplankton samples is next performed with a compound microscope capable of magnification from 40 to 1,000 times and using phase-contrast illumination. Approximately 15 minutes are allowed for the phytoplankton to settle to the bottom of the S-R Cell before enumeration. Phytoplankton are enumerated in a total of 10 fields described by an ocular micrometer. At 200X magnification, the ocular field measures 0.3136 square millimeters in area (previously calibrated with a stage micrometer) and the fields are selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

Phytoplankton densities are expressed as Areal Standard Units (ASU; equivalent to 400 square microns) per milliliter. The area of each specimen viewed in each counting field is estimated using the ocular micrometer (the ocular field is divided into a 10 by 10 grid, each square in the grid having an area of 3,136 square microns or 7.84 ASU at 200X magnification). In the case of taxa which form gelatinous envelopes or are enclosed in a colonial mucilage, such as *Microcystis*, the area of the envelope is included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, is estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates, are not included in the count.

Figure 8
2004 Plankton Monitoring at Wachusett Reservoir



4.4.3 MONITORING RESULTS

Monitoring results for 2004 document an atypical pattern of phytoplankton succession marked by an unusually intense bloom of the colonial, flagellated chrysophyte *Chrysosphaerella* during July persisting to mid-August (Figure 8). This bloom was accompanied by a record number of complaints of unpleasant “metallic” taste and odor among water consumers throughout the MWRA distribution system (total of 1,010 reported in July declining to 264 in August). Details of phytoplankton dynamics in 2004 are given below.

The typical spring diatom bloom which usually attains densities of over 1,000 ASU/mL after ice-out never materialized in 2004 (Figure 8). Total densities ranged from 66 to 609 ASU/mL from March through May with an average density of only 306 ASU/mL. In June, total densities increased somewhat ranging from 281 to 801 ASU/mL, but still with an average density for the month of only 553 ASU/mL.

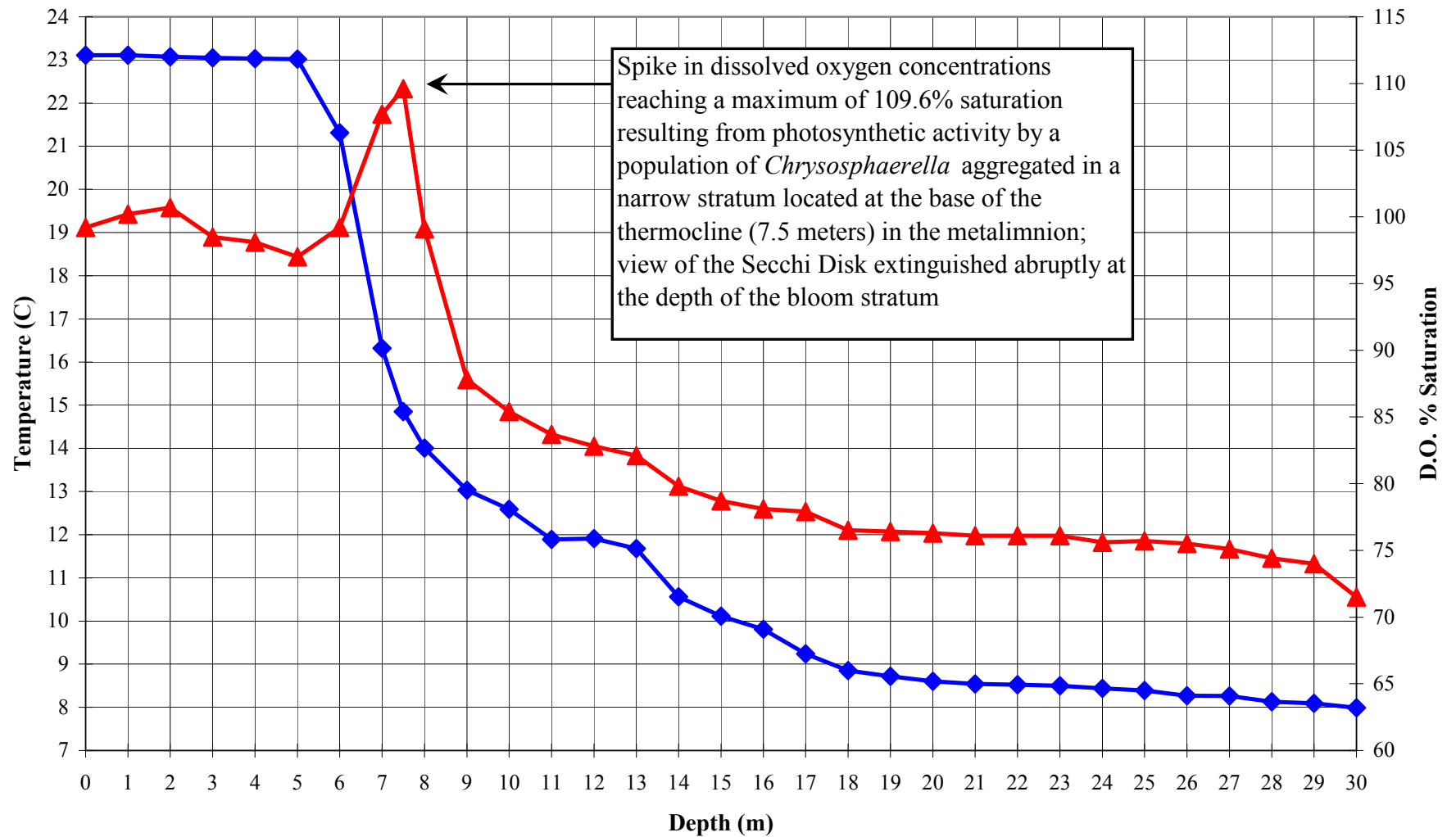
According to historical data, this pattern of unusually low diatoms densities in the spring predisposes the reservoir ecosystem to a bloom of the problematic “taste and odor” chrysophyte *Synura* later in the summer or early fall (Worden and Pistrang, 2003). Both diatoms and *Synura* require silica to make their unique cellular structures. The inverse relationship between maximum spring diatom densities and subsequent growth of *Synura* is likely due to diatom growth and subsequent sedimentation functioning to deplete this nutrient. Replenishment of silica to the water column after a vigorous diatom bloom in spring apparently does not occur in time to support significant growth of *Synura* populations later in the year.

Chrysosphaerella is another chrysophyte that, like *Synura*, requires silica. Thus, the pattern of phytoplankton dynamics in 2004 reinforces the finding of an inverse relationship between the intensity of the spring diatom bloom and blooms of chrysophytes requiring silica later in the year.

The remarkable 2004 bloom of *Chrysosphaerella* was initially detected on Tuesday, July 6th at a density of 1,432 ASU/mL focused in a narrow stratum at a depth of around 7 meters. Individual cells of *Chrysosphaerella* possess a flagellum, thus colonies are motile and were able to adjust their vertical position in the water column to coincide with the sharp temperature gradient that exists at the interface between the epilimnion and metalimnetic interflow. Noteworthy on this initial day of detection was the exceptional water transparency measured by a Secchi Disk lowered through the water column until, upon reaching the depth of the bloom, visibility of the Secchi Disk was rapidly extinguished (within a span of about 30 centimeters or one foot).

The peak density of *Chrysosphaerella* was observed the next day (July 7th) at 1,949 ASU/mL. Water column profile measurements showed a sharp spike in dissolved oxygen concentration (109.6 % saturation) at a depth of 7.5 meters where this sample was collected (Figure 9). The narrow stratum of elevated dissolved oxygen concentrations resulted from photosynthetic activity by billions of *Chrysosphaerella* colonies aggregated at this discrete depth in the water column. This type of dissolved oxygen profile is known as a “positive heterograde curve” and is characteristic of many temperate lakes and reservoirs (Wetzel, 1983).

Figure 9
Water Column Profile at Station 3417 (Basin North) on July 7, 2004



Profile measurements recorded July 7th and afterward confirmed that the bloom stratum was only about 0.3 to 0.5 meters thick and was focused at the bottom of the steepest portion of the thermocline at a depth of 7.5 meters where the water temperature was about 15°C (Figure 9). Earlier profile measurements through June 30th showed no sign of a metalimnetic spike in dissolved oxygen concentrations although *Chrysosphaerella* colonies were observed at relatively low, but gradually increasing densities (21-194 ASU/mL) since June 9th.

The metalimnetic spike of dissolved oxygen and the abrupt extinguishing of Secchi visibility at the depth of the “growth plate” were consistent features of the bloom which would persist for the next seven weeks. Field observations of an informal nature are also noteworthy; samples of the bloom stratum collected in a transparent acrylic Van Dorn bottle appeared colorless and crystal clear to the naked eye and had no taste or odor despite the presence of very high densities of *Chrysosphaerella* confirmed later by microscopic analysis.

A search of the literature on metalimnetic phytoplankton blooms revealed a remarkably similar scenario documented by researchers in Canada. Pick et al. (1984a) studied metalimnetic *Chrysosphaerella* blooms occurring in July (1979-81) in Jack Lake, Ontario where maximum densities reached 10,000 cells/mL or an estimated 2,000 ASU/mL. They observed colony densities increasing in epilimnion in June prior to formation of a metalimnetic “peak” and attribute this increase mostly to a process of excystment. Then, over a four day period in July, *Chrysosphaerella* biomass accumulated in a metalimnetic stratum centered around a depth of 7 meters due to a “very rapid decent” of colonies from the epilimnion. Thus, aggregation of colonies in the bloom stratum resulted from their downward migration (not from “in situ” growth below the thermocline) with few colonies remaining in the epilimnion.

These researchers considered the “sudden movement” of colonies into the metalimnion as “primarily a behavioral response, affected by temperature and light.” The thresholds for these variables identified as potential triggers for the migratory response were an epilimnetic water temperature approaching 24°C and cumulative solar radiation in June having included nine “bright” days (exceeding 600 Langleys/day as measured with a pyrhelimeter; one Langley = 1 calorie per square centimeter).

The *Chrysosphaerella* blooms described by Pick et al. (1984a) are strikingly similar to the bloom in Wachusett Reservoir in terms of depth and narrowness of the bloom stratum, seasonal timing (formation of metalimnetic peak in July), and duration (declining in August). Colonies were gradually proliferating in the Wachusett epilimnion in June prior to formation of the metalimnetic bloom stratum and few colonies were left in the epilimnion after the bloom stratum had formed as shown by sampling and Secchi data.

Biomass accumulation in the Wachusett bloom stratum is compatible with a “very rapid decent” from the epilimnion over a period of a few days. Integration of the average epilimnetic density on June 30th over depth to the bloom stratum matches almost exactly the peak density of 1,908 ASU/mL observed on July 7th. Also, on June 30th, the Wachusett epilimnion was warmed to within three degrees of the temperature threshold (24°C) identified for triggering the “behavioral response” of downward migration.

In a companion paper (Pick et al., 1984b), the Canadian researchers demonstrate that the metalimnetic stratum in which *Chrysosphaerella* aggregated did not provide nutritional benefits, especially in terms of greater availability of phosphorus. Phosphorus concentrations were uniformly low throughout the epilimnion and metalimnion. Phosphorus demand, as measured by turnover rates of radiotracer phosphate, was lower in the metalimnetic peak immediately after its formation than in the epilimnion. In other words, the multitude of *Chrysosphaerella* colonies that had migrated to the metalimnion did not experience phosphorus scarcity in comparison to the phytoplankton remaining in the epilimnion despite uniformly low concentrations.

Over time, after the peak first appeared, demand for phosphorus steadily increased in the bloom stratum until it was comparable to the epilimnion by the end of August. Associated with this increasing metalimnetic demand for phosphorus was a decline in the density of the population until phosphorus deficiency eventually resulted in the demise of the bloom. Measurements of polyphosphate, a cellular form of stored phosphorus, indicate that *Chrysosphaerella* migrated to the metalimnion with internal reserves of phosphorus and only became phosphorus deficient when these reserves had been depleted. As with the Canadian research previously discussed, this interpretation of *Chrysosphaerella* nutritional status corresponds with the bloom scenario at Wachusett Reservoir where nutrient concentrations are known to be low and relatively uniform throughout the epilimnion and metalimnion (with an average total phosphorus concentrations of 7 – 8 µg/L respectively at Station 3417 – Basin North).

Based on the findings discussed above, it is evident that *Chrysosphaerella* inhabiting the Wachusett epilimnion migrated rapidly from the epilimnion to the bloom stratum in the few days prior to and during the July 4th weekend. This migration was primarily an avoidance response to intensifying solar radiation and warming epilimnetic temperatures and not attraction to nutritional resources. Aggregation at a depth of 7.5 meters indicates that this position in the thermocline provided *Chrysosphaerella* with the optimal combination of light intensity and cooler temperatures.

Additionally, the position of the bloom stratum was at the base of the steepest portion of the thermocline where the density gradient offers the greatest resistance to mixing from circulation patterns occurring above in the epilimnion. It is likely that this position provided a “refuge” from wind-induced turbulence and attendant dislocation throughout the epilimnion. Colonies above this depth would have to expend greater amounts of energy in swimming to counteract upward circulation into the epilimnion.

It is instructive to note that the onset of multiple complaints of disagreeable “metallic” taste and odor occurred on July 5th after *Chrysosphaerella* had aggregated in the metalimnion, whereas no complaints were reported when the organism was proliferating in the epilimnion. This indicates that the epilimnetic population was not subject to significant withdrawal into Cosgrove Intake where the inlet gates span an opening between depths of 13.4 and 15.2 meters (44 and 50 feet). In contrast, downward migration to a metalimnetic bloom stratum located beneath the steepest portion of the thermocline apparently made the population susceptible to entrainment in deep circulation patterns associated with water withdrawal at Cosgrove Intake.

Interestingly, monitoring efforts conducted concurrently at Station 3412 (Basin South) showed no sign of the bloom in profile measurements and, in fact, a record for Secchi transparency at that location of 31 feet (9.5 meters) was recorded on July 7th. Subsequent monitoring confirmed that the bloom was limited to the northern basin (northeast of the “Narrows”).

In response to taste and odor complaints received starting over the July 4th holiday weekend, MWRA mobilized for copper sulfate application which was initially conducted on July 7th in the “treatment area” adjacent to Cosgrove Intake. Over the course of the bloom, copper sulfate was applied on five dates on July (7th, 12th, 20th, 29th, and 30th) and three dates in August (6th, 13th, and 19th). Post-application monitoring in the treatment area throughout the duration of the bloom showed treatment effectiveness at depth to be inconsistent.

Data from Station 3417 (Basin North), which was monitored as a reference station outside the area of copper sulfate applications, document a steep decline in bloom densities in the two weeks following its peak on July 7th. Day to day variability in densities observed at this station was likely due to difficulties in collecting a grab consistently at the target depth rather than fluctuations in *Chrysosphaerella* abundance; triggering the sampling device above or below the narrow “growth plate” would miss most of the organisms.

A brief surface bloom of the cyanophyte *Anabaena* overlapped the metalimnetic *Chrysosphaerella* bloom on July 29th. This *Anabaena* bloom formed a surface “slick” of green specks typical of its manifestation on a calm day, but was unusual in its seasonal timing because it generally appears in June rather than late July.

The metalimnetic *Chrysosphaerella* bloom persisted at greatly reduced densities (generally less than 200 ASU/mL) into August. Sampling conducted on August 17th at widely dispersed locations across the northern basin confirmed it to be a large-scale phenomenon. Specifically, profiles measurements were recorded near the Narrows in the southwest portion of this basin, west of Cemetery Island in the northwest portion of this basin, north of the “Shallows” in the northeast portion of this basin, and in the southeast portion of this basin adjacent to Mile Hill Road as well as at Station 3417 (Basin North). These measurements documented metalimnetic spikes in dissolved oxygen concentrations at all locations and confirmatory grab samples collected at a depth of 7 meters at each location were invariably dominated by *Chrysosphaerella*.

Continued monitoring at Station 3417 (Basin North) revealed the *Chrysosphaerella* bloom to finally subside due to natural causes, likely due to exhaustion of cellular reserves of phosphorus stored as polyphosphate (Pick et al., 1984b) and similarly deficient supplies of phosphorus in the water column. It was last observed on August 19th at a density of 33 ASU/mL and the residual profile spike in dissolved oxygen concentrations had dissipated by August 25th. In the last two weeks of the bloom, *Chrysosphaerella* colonies often appeared unhealthy with individual dead cells present. Also during this time, the organism was frequently observed as colony fragments or as individual cells disassociated from a colony.

Phytoplankton densities remained relatively low during September and, especially, in early October when an average density of only 126 ASU/mL coincided with a record Secchi transparency measurement of 30.5 feet (9.3 meters) at Station 3417 (Basin North). Coinciding with the initial stage of “turnover” when the epilimnion mixed with the metalimnetic interflow in late October, diatoms (mostly *Asterionella*) started to increase in abundance (Figure 8). Erosion of the residual hypolimnion by mixing and the eventual homogenization of its store of nutrients into the entire water column in early November fueled a steady bloom of diatoms that quickly reached densities of over 1,000 ASU/mL. This increase continued until mid-January when densities exceeded 1,500 ASU/mL just prior to the formation of ice cover over the reservoir surface and the cessation of monitoring efforts.

4.5 MACROPHYTES

4.5.1 THE THREAT OF EURASIAN WATER-MILFOIL

The Wachusett Reservoir system is a major component of the drinking water supply for greater Boston. In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum*; referred to subsequently as “milfoil”) was observed for the first time in Upper Thomas Basin, a small basin in the upper reaches of the reservoir system. Milfoil is an exotic, invasive species of macrophyte known to aggressively displace native vegetation and grow to nuisance densities with associated impairments to water quality. Prior to 2001, this plant was restricted to the uppermost component of the reservoir system, Stillwater Basin, where its distribution has been monitored since 1999.

The expansion of milfoil into Upper Thomas Basin represents a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. The water quality implications of such an event are serious and include increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. These increases result from the function of this plant and macrophytes in general as nutrient “pumps,” extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter.

This function is especially intense with milfoil due to its characteristically rapid and prolific growth habit. Nutrient release occurs during most life cycle stages, but especially during senescence and death. Milfoil also releases nutrients and organic matter during canopy formation (lower leaves and branches are sloughed as upper stems grow horizontally along the surface) and when undergoing a propagation process known as autofragmentation. Autofragments are stem segments with adventitious roots at the nodes that float upon abscission and are the plant’s most important mode of reproduction and dispersal. Autofragments of milfoil eventually sink to the bottom and are capable of colonizing littoral zone areas having only minimal deposits of organic sediment.

4.5.2 WACHUSETT RESERVOIR MILFOIL CONTROL PROGRAM

The 2001 expansion of milfoil into Upper Thomas Basin prompted DCR to design a milfoil control program which was implemented in 2002 and has continued to the present. Descriptions of milfoil control efforts in previous years are provided in their annual reports. Milfoil control efforts in 2004 consisted mainly of a continuation of the primary control technique of hand-harvesting. Hand-harvesting was conducted by Aquatic Control Technology (ACT) of Sutton, MA. Additionally, GeoSyntec Consultants of Boxborough, MA conducted a second post-stocking survey of weevil activity in Stillwater Basin and submitted a final report to conclude the biological control program initiated last year. Details of the 2004 milfoil control program are summarized below.

Hand-Harvesting of Eurasian Water-milfoil: Summary of ACT Efforts in 2004

- Preliminary GPS survey of Upper Thomas Basin conducted on May 11th
- Hand-harvesting conducted during nine days between July 6th and September 13th mainly focused on Upper Thomas Basin, but also including Thomas Basin proper
- Total diver-hours expended = 135.5 (compared to 93.25 hours in 2003 and 496.5 hours in 2002)
- Estimate of total milfoil plants removed = 7,424 (compared to 3,251 plants in 2003 and an estimated 75,000 - 100,000 plants removed in 2002)
- The alien Fanwort (*Cabomba caroliniana*) has become more abundant in Upper Thomas Basin and is removed along with milfoil
- Post-harvesting GPS survey of Upper Thomas Basin conducted on September 24th documents nearly total control of milfoil (also routine scouting by DCR finds no milfoil in main basin)

Biological Control of Eurasian Water-milfoil: Final Monitoring Report on Weevil Introduction by GeoSyntec (September, 2004)

- Final post-stocking monitoring survey of Stillwater Basin conducted on July 8th
- Qualitative field observations of the stocking site indicate a decline in milfoil abundance and vigor (poor coloration) compared to 2003
- Lab analysis of milfoil stems from the stocking site shows an increase in the presence of weevil life stages (eggs, larvae, and adults) compared to 2003
- Qualitative field observations of the control site are similar to those recorded in 2003
- Results of lab analysis of milfoil stems from the control site are inconsistent with data from 2003 when damage to stems and weevil eggs were observed (this was interpreted as evidence of a pre-existing weevil population); weevil damage and life stages were inexplicably absent from the control site in 2004

In addition to the activities of consultants summarized above, DCR staff deployed floating fragment barriers (purchased in 2002) at strategic “bottleneck” locations to restrict the movement of milfoil autofragments into downgradient portions of the reservoir system. These locations are where floating fragment barriers were initially deployed in 2002 and consist of the railroad bridge between Stillwater Basin and Upper Thomas Basin and the Beaman Street Bridge between Upper Thomas Basin and Thomas Basin proper. In 2004, floating fragment barriers were deployed in May and retrieved in November.

4.5.3 PLANS FOR MILFOIL CONTROL EFFORTS IN 2004

The invasive nature of milfoil necessitates a long-term commitment to annual control efforts in the upper reaches of the Wachusett Reservoir system if its dispersal into the main basin is to be prevented. To meet this challenge, DCR and MWRA are working collaboratively to design and implement future control programs.

Next year, during the 2005 growing season, plans call for a resumption of intensive hand-harvesting in Upper Thomas Basin. Early efforts will focus on harvesting plants in areas known to support regrowth of milfoil and the few specimens not removed last season. Dive crews will be available for hand-harvesting the entire summer in the likely event that regrowth occurs subsequent to initial harvesting efforts. Associated with hand-harvesting efforts, DCR staff will continue routine scouting for milfoil throughout the reservoir system to identify and target any pioneering specimens found in new areas. Also, DCR staff will redeploy the floating fragment barriers at their strategic “bottleneck” locations as done in previous years.

Another component of the 2005 control program will be maintenance of the benthic barriers installed in 2002 at the northern end of Upper Thomas Basin. This installation consists of a total of 72 panels of barrier material, each measuring 1,200 square feet (24' x 50'). These panels now have a slight accumulation of sediment on top of them and need to be cleaned. This entails SCUBA divers removing the lengths of steel “re-bar” used to anchor each panel, inverting or flipping each panel over, and then re-anchoring it in its original position. Some of the panels in the shallowest portion of the basin will be removed as a first step in restoring littoral zone habitat to its natural state now that the milfoil infestation in this portion of Upper Thomas Basin has been suppressed.

A third component of the 2005 control program will focus on Stillwater Basin and consists of a preliminary feasibility study to assess the potential for sediment and plant removal via dredging or other mechanical means. Key components of this study include sediment characterization, a macrophyte survey, mapping, cost analysis, and impact assessment.

5.0 SUMMARY OF SITE INVESTIGATIONS

A total of 110 sites were investigated during 2004. A majority of the issues at these locations were related to residential or commercial development (including new construction, repairs and additions, and septic system improvements) and resulted in problems with sedimentation and erosion, encroachment, or bacterial contamination. Other problems addressed during 2004 included illegal dumping, spills of hazardous materials, road reconstruction, fecal contamination from agricultural activities, wetland encroachment, sewer overflows, forestry operations, right-of-way vegetative management, and sedimentation from sewer construction.

Problems at sixty-one of the sites were addressed during 2004 and are now considered resolved. Thirty-nine sites are currently on watch status. Work at these sites is being monitored and additional activities are necessary in some cases, but the OWM is confident that successful resolution of these issues will occur. Problems at these sites are primarily associated with residential construction (additions, garages, new single-family homes, and septic repairs) and are also regulated under the jurisdiction of the Watershed Protection Act.

Ten sites originally investigated during 2004 remain active. Three involve construction issues, including two single-family additions plus the impending demolition of an old factory and the subsequent planned replacement with a large number of residential units. Two wetland issues are outstanding. One involves sedimentation and the other illegal removal of vegetation. There are two roadway issues currently under review, a bridge repair over the Stillwater River and the maintenance and improvement of the I190 stormwater management basins. A cesspool replacement done without permits or review is currently under investigation, as is encroachment on DCR land involving an illegal drainage pipe. The replacement of valves at the Oakdale Power Station is also an active project and staff remain involved. There are also a number of additional locations from previous years that remain active as well, along with a number of investigations initiated early during 2005.

6.0 SAMPLING PLAN FOR 2005

The Wachusett watershed sampling program for 2005 will once again include special studies, enforcement actions, incident response, and routine sampling and analysis. The routine sampling program will attempt to separate out the effects of storm events on tributary and reservoir water quality from standard dry weather water quality data using detailed precipitation data from three stations in or near the watershed. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform and conductivity will be measured weekly at fifty-four stations on thirty tributaries during dry weather. This is a continuation of the expanded sampling program that has been in place since last year and is an attempt to collect data from a greater number of stations to be able to address issues that have been identified in previous water quality summaries and Environmental Quality Assessment reports. Quarterly nutrient samples will again be collected from nine tributary stations with available flow data. Separate wet weather sampling of eight major tributaries will be done to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then the eight stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries. An attempt will be made to relate seasonal effects on water quality responses to storm events.

Monthly temperature, dissolved oxygen, pH, and conductivity profiles will be taken at three reservoir stations (3417-Basin North, 3412-Basin South, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Plankton samples will be collected weekly or biweekly at multiple depths from the Cosgrove Intake or mid reservoir station 3417, and quarterly from Thomas Basin and mid reservoir station 3412. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and silica will be collected quarterly from 3417, 3412, and Thomas Basin. Fecal coliform bacteria samples will no longer be collected at the Cosgrove Intake by DCR. MWRA staff will continue to collect regulatory samples daily five days per week from an internal tap.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, remains the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly bacterial transect sampling will be done during ice-free periods to help further understand the effect of water movement on fecal coliform levels throughout the reservoir. A consultant study of reservoir hydrodynamics is proposed for the upcoming year to help improve our understanding of this important issue.

Sampling of the Pinecroft area drainage basin will continue as part of the routine weekly sampling program in order to evaluate the impacts of sewerage on water quality in a small urbanized tributary to the Wachusett Reservoir. Samples will also be collected from two similar sized drainage areas with different land uses for comparative purposes. Initial sampling in the Pinecroft subbasins established baseline and stormwater nutrient and bacteria levels and profiled water quality prior to sewer construction. Sewers are now in the ground and many of the homes in the area have been connected. Improvements in water quality are expected. Additional areas that have recently been sewerage will also be examined to see if improvements can be detected, and historical data will be analyzed to help detect any possible positive trends.

Additional sampling recommended in three previously published Environmental Quality Assessment Reports (Reservoir, Thomas Basin, Quinapoxet) will be done as needed during 2005, along with sampling to support the Stillwater Environmental Quality Assessment (in progress). Samples will also be collected as needed when water quality conditions change and problems are noted, and to help locate sources of contamination. Samples will also be collected to support any potential enforcement actions required by other OWM staff.

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